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THE UNIVERSITY OF ALBERTA

PHYSICAL AND CHEMICAL GROWTH OF CARCASS TISSUE IN THE PIG

BY

© ROBERT JOHN RICHMOND

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF ANIMAL SCIENCE

EDMONTON, ALBERTA

SPRING, 1976

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Physical and Chemical Growth of Carcass Tissues in the Pig", submitted by Robert John Richmond in partial fullfilment of the requirements for the degree of Doctor of Philosophy in Animal Genetics.

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ABSTRACT

Two studies were conducted to determine patterns of tissue growth and development, relative growth patterns of individual muscles and chemical composition of muscles in swine and to assess the effect of liveweight, breed, sex, ration and feeding level on these patterns.

In Study 1, complete anatomical dissection was carried out on the left side of carcasses of seventy-three pigs taken from an experiment which involved 144 barrows and gilts of Duroc x Yorkshire (DY), Hampshire x Yorkshire (HY), and Yorkshire x Yorkshire (YY) breeding, fed either a high energy (HE) (3652 kcal DE/kg and 19.9% CP) or a low energy (LE) 2757 kcal DE/kg and 15.3% CP) ration for two one-hour periods per day and slaughtered at 68, 91 and 114 kg liveweight. Part of the study also included data from 19 Hampshire x Yorkshire barrows and gilts killed at the same liveweights but fed the two rations on an ad libitum basis. To establish a starting point, nine barrows and eight gilts of the same breed groups were slaughtered at 23 kg liveweight.

In Study 2, complete anatomical dissection was carried out on the left side of carcasses of seventy-two Yorkshire x Lacombe (YL) and Yorkshire x Lacombe-Yorkshire (YLY) barrows and gilts fed a ration containing 2951 kcal DE/kg and 15.5%

CP at one of three feeding levels (3.2, 3.7 or 4.2% of body weight) and slaughtered at 68, 91 or 114 kg liveweight. In most comparisons data from the 23 kg liveweight group in Study 1 were used as starting or reference points for the data in Study 2.

A normal pattern of tissue growth occurred in each study. Bone growth was relatively slow and muscle growth relatively fast. Fat deposition paralleled muscle growth up to 91 kg liveweight and thereafter exceeded muscle growth in absolute amount. Gilts had a greater proportion of muscle and less of fat than did barrows. In Study 1 the influence of HE and LE rations were similar to those of barrows and gilts respectively. In Study 2, pigs fed at the 3.2% level had a greater proportion of muscle and less of fat than those fed at the 3.7 or 4.2% feeding levels.

Muscle distribution changed slightly between 23 and 68 kg liveweight but remained relatively constant thereafter. Interactions effected the percentage of some muscle groups. However, the growth patterns of individual muscles in these studies did reveal a direct relationship between differential muscle development and function.

Five muscles from each animal (M. extensor carpi radialis (ECR), M. longissimus dorsi (LD), M. obliquus internus abdominus (OIA), M. rhomboideus (RH), M.

semitendinosus (ST) were analysed for moisture, nitrogen, fat and ash according to AOAC (1965) methods. Each muscle represented different relative growth impetus patterns.

Similarities were observed between the pattern of muscle and fat deposition in the carcass and the pattern of nitrogen and fat deposition in muscle. Concentrations of water, nitrogen, fat and ash in some muscles were effected by interactions. Chemical composition of muscle appeared to be related to muscle function. Those muscles responsible for mobility had greater concentrations of nitrogen and less of fat than the more sedentry support muscles.

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Table of Contents

	Page
General Introduction.....	1
I. Tissue Growth in the Carcass	
A) Introduction.....	3
B) Materials and Methods.....	6
1) Study 1.....	6
2) Study 2.....	8
C) Results and Discussion.....	9
1) Tissue growth.....	9
2) Influence of liveweight on tissue growth....	10
3) Influence of breed on tissue growth.....	14
4) Influence of sex on tissue growth.....	16
5) Influence of ration and feeding level on tissue growth.....	16
6) Interaction effects on tissue growth.....	17
7) Considerations in pork production.....	23
II. Relative Growth Patterns and Distribution of Muscle	
A) Introduction.....	28
B) Materials and Methods.....	29
C) Results.....	31
D) Discussion.....	62
III. Growth of Chemical Components in Muscle	
A) Introduction.....	71
1) Chemical changes in body composition.....	71

2) Growth patterns of chemical components in the body..... 73
3) Growth patterns of chemical components in muscle..... 77
4) Factors effecting growth patterns of chemical components..... 83
4.1. Breed effects..... 83
4.2. Sex effects..... 84
4.3. Nutritional effects..... 85
B) Materials and Methods..... 89
C) Results..... 90
1) Influence of liveweight..... 91
2) Influence of breed..... 99
3) Influence of sex..... 100
4) Influence of ration and feeding level..... 101
5) Interaction among liveweight, breed, sex, ration and feeding level..... 102
D) Discussion..... 116
General Summary and Conclusions..... 129
Bibliography..... 134
Appendix I..... 154

LIST OF TABLES

Page

Table 1. Influence of liveweight, breed, sex and ration on carcass composition and tissue growth in swine: (Study 1)..... 12

Table 2. Influence of liveweight, breed, sex and feeding level on carcass composition and tissue growth in swine: (Study 2)..... 13

Table 3. Mean carcass grade indexes (%) as influenced by interactions of slaughter weight by sex and slaughter weight by ration: (Study 1)... 19

Table 4. Slaughter age (days) and muscle per day of age (g) as influenced by interaction of sex by ration: (Study 1)..... 19

Table 5. Final weight per day of age (g) as influenced by breed by sex and ration by sex interactions: (Study 1)..... 19

Table 6. Carcass weight per day of age (g) as influenced by breed by ration and sex by ration interactions: (Study 1)..... 20

Table 7. Fat per day of age (g) as influenced by by breed by sex interaction: (Study 1)..... 20

Table 8. Sex by feed level interaction on fat per day of age (g): (Study 2)..... 22

Table 9. Sex by breed interaction on feed conversion ratio: (Study 2)..... 22

Table 10. Relative proportions of muscle and fat in barrow and gilt carcasses at different liveweights: (Study 1 and 2)..... 26

Table 11. "Standard muscle groups" as a percentage of weight of total side muscle in barrows and gilts of three breeds fed low and high energy rations and slaughtered at four liveweights: (Study 1)..... 32

Table 12. Muscle group percentages differing significantly between barrows and gilts slaughtered at 23 kg liveweight: (Study 1).. 33

Table 13. Percentages in muscle group 7 (thorax to thoracic limb) showing interactions of sex by ration and sex by breed ($P<0.05$): (Study 1)..... 35

Table 14. "Standard muscle groups" as a percentage of weight of total side muscle in barrows and gilts of two breed groups fed at three levels and slaughtered at three liveweights: (Study 2)..... 36

Table 15. Weights by feeding level interaction on percentage muscle in three muscle groups: (Study 2)..... 38

Table 16. Breed by feeding level interaction on percentage muscle in two muscle groups: (Study 2)..... 40

Table 17. Weight by breed interaction on percentage muscle in two muscle groups: (Study 2)..... 42
Table 18. Individual muscle weight and standard errors as a percent of total muscle at each of four liveweights: (Study 1 and 2)..... 43
Table 19. Growth coefficients and standard errors for individual muscles and nine "standard muscle groups" with comparisons of other data..... 51
Table 20. Chemical composition of pig carcasses as reported by different researchers..... 74
Table 21. Chemical composition of carcasses from other species as reported by different researchers 75
Table 22. Composition of various muscles or carcass joints in pigs as reported by different researchers..... 79
Table 23. Chemical composition of various muscles or carcass joints in other species as reported by different researchers..... 81
Table 24. Chemical composition of five muscles on dry matter basis: (Study 1)..... 95
Table 25. Chemical composition of five muscles on dry matter basis: (Study 2)..... 96
Table 26. Ratios of chemical components in five muscles as influenced by liveweight, breed, sex and ration: (Study 1)..... 97
Table 27. Ratio of chemical components in five muscles

as influenced by liveweight, breed, sex and feeding level: (Study 2)..... 98

Table 28. (a) Weight by breed interaction on % nitrogen in the RH muscle: (Study 1)..... 103

(b) Weight by breed interaction on N/F ratio in the RH muscle: (Study 1)..... 103

(c) Weight by breed interaction on % ash in the ECR muscle: (Study 2)..... 103

(d) Weight by breed interaction on % ash in LD muscle: (Study 2)..... 103

Table 29. (a) Weight by sex interaction on % fat in the LD muscle: (Study 1)..... 104

(b) Weight by sex interaction on % nitrogen in the LD muscle: (Study 2)..... 104

(c) Weight by sex interaction on F/W ratio in the LD muscle: (Study 2)..... 104

(d) Weight by sex interaction on % nitrogen in the OIA muscle: (Study 2)..... 104

(e) Weight by sex interaction on N/F ratio in the ST muscle: (Study 2)..... 104

Table 30. (a) Weight by ration interaction on % fat in the ECR muscle: (Study 1)..... 107

(b) Weight by feed level interaction on % fat in the ECR muscle: (Study 2)..... 107

(c) Weight by feed level interaction on % fat in the OIA muscle: (Study 2)..... 107

(d) Weight by ration interaction on % moisture in the ECR muscle: (Study 2)..... 107
(e) Weight by feed level interaction on N/F ratio in the ECR muscle: (Study 2)..... 108
(f) Weight by feed level interaction on F/W ratio in the ECR muscle: (Study 2)..... 108
(g) Weight by feed level interaction on N/W ratio in the ECR muscle: (Study 2)..... 108
(h) Weight by feed level interaction on % nitrogen in the LD muscle: (Study 2).... 109
(i) Weight by feed level interaction on N/F ratio in the LD muscle: (Study 2)..... 109
(j) Weight by feed level interaction on % ash in the ST muscle: (Study 2)..... 109
Table 31. (a) Breed by sex interaction on % fat in the LD muscle: (Study 1)..... 111
(b) Breed by sex interaction on N/F ratio in the RH muscle: (Study 1)..... 111
Table 32. (a) Breed by feed level interaction on % fat in the ECR muscle: (Study 2)..... 113
(b) Breed by feed level interaction on % nitrogen in the ECR muscle: (Study 2)... 113
(c) Breed by feed level interaction on N/F ratio in the ECR muscle: (Study 2)..... 113
(d) Breed by feed level interaction on F/W ratio in the ECR muscle: (Study 2)..... 113

(e) Breed by feed level on % fat in the ST muscle: (Study 2)..... 114
(f) Breed by feed level interaction on % nitrogen in the ST muscle: (Study 2).... 114
(g) Breed by feed level interaction on N/F ratio in the ST muscle: (Study 2)..... 114
(h) Breed by feed level interaction on F/W ratio in the ST muscle: (Study 2)..... 115
(i) Breed by feed level interaction on % fat in the OIA muscle: (Study 2)..... 115
(j) Breed by feed level interaction on % nitrogen in the RH muscle: (Study 2).... 115

Table 33. Muscles ranked in decreasing order of relative proportions of nitrogen, water and fat averaged over three liveweights: (Studies 1 and 2)..... 124

Appendix I

Table 1. Means and standard errors of chemical component weights (g) of 5 muscles as influenced by liveweight, breed, sex and ration: (Study 1).... ii

Table 2. Means and standard errors of chemical component weights (g) of five muscles as influenced by liveweight, breed, sex and feeding level: (Study 2)..... iii

LIST OF FIGURES

		Page
Figure 1.	Carcass muscle, fat and bone weights relative to liveweight in pigs: (Studies 1 and 2).....	11
Figure 2.	Relative growth impetus patterns of pigs (a) compared to cattle and sheep (b).....	58
Figure 3.	Chemical composition of pigs at different liveweights (plotted from data cited by Mitchell and Hamilton, 1929).	76
Figure 4.	Average weight of chemical components (g) relative to liveweight.....	92
Figure 5.	Average percent of chemical components of five muscles relative to liveweight.....	93

GENERAL INTRODUCTION

An increasing demand for animal protein coupled with a decreasing availability of animal food stuffs may, in future, dictate quite radical changes in animal production and product processing. Species of animals, which up to now, have been considered articles of pleasure or recreation, but which, because of evolutionary adaptation, may have certain advantages over present meat-producing species and will take on a new role in the production of animal protein.

Maintaining species, such as the pig, which compete directly for human food stuffs may only be justified if means are found by which the muscle to fat ratio (and therefore the relative protein content) of the carcass might be increased. Any attempts to change the proportions of muscle and fat in the pig carcass will require a more complete knowledge of the physical and chemical growth of these tissues relative to tissue function. In addition the influence of various genetic and environmental factors on tissue growth in pigs must be delineated more fully.

The objective of this study was to examine the relative growth patterns of major carcass tissues, individual muscles and the major chemical components of muscle in pigs and to evaluate some of the deviations that might occur in these growth patterns as a result of various genotypic and

environmental factors.

I. Tissue Growth in the Carcass

A) Introduction

The term growth has many connotations and as suggested by Kunkel (1961) may mean anything from reproduction to cellular division, migration, or expansion to increase in body size. In domestic animals growth has usually referred to an increase in body size over some period of time. Fowler (1968) considered this the first and simplest means of describing growth. A second consideration of the growth process, which might be considered as development, is the change in form of the body as a result of the relative growth rates of various body components. D'Arcy Thompson (1917) suggested that body form followed the development of body components as dictated by function and Kunkel (1961) considered the growth process to be highly plastic and responsive to genetic and environmental forces. Function therefore may, over time, dictate the rate of differential tissue development and the form and growth of animals within a population.

In the domestic meat animal the three major body tissues of economic importance are muscle, fat and bone. The very detailed Cambridge studies conducted by Hammond (1932), McMeekan (1940 a, b, c) and Palsson and Verges (1952a, b) recognized and described a differential development of these three tissues as animals matured. Following birth, bone is

the earliest developing tissue, followed by muscle and then fat. Bone provides both a supporting frame for other tissues and a mobility function while muscle provides a supporting connection between bones and a work function. Because of the necessity for mobility very soon after birth, bone and muscle develop relatively quickly. Fat provides an energy store but because the young animal is able to obtain its initial energy requirements through suckling, the rate of fat deposition in the body does not show any dramatic increases until late in the suckling period or sometime thereafter.

The relative proportions of muscle, fat and bone in a carcass change as liveweight increases and may be influenced by both genetic and environmental factors. In pigs the proportion of muscle decreases in the carcass and fat increases as liveweight increases (Atkinson and Klein, 1946; Allen et al, 1961; Bowland and Berg, 1959; Braude et al, 1963; Brooks et al, 1964; Buck, 1963; Bull and Longwell, 1929; McCampbell and Baird, 1961; Mitchell and Hamilton, 1929).

Breed and type of pig affect carcass composition (Aunan et al, 1961; Berg, 1958; King, 1963; King, 1966; Lucas and Calder, 1956; Plank and Berg, 1963; Sayre et al, 1963; Whiteman et al, 1951).

Barrows have a greater proportion of carcass fat and smaller proportion of muscle than do gilts (Bruner et al, 1958; Self et al, 1957; Robinson, 1965; Zobrisky, 1961).

Differences in proportions of muscle and fat in the carcass may be a result of energy levels of the ration or level of feeding (Baird and McCampbell, 1962; Brooks et al, 1964; Cooke et al, 1972; Davies and Lucas, 1972a, b; Lodge et al., 1972; Jones and Pond, 1964; Wagner et al, 1963).

The above studies would appear to have satisfied many of the questions surrounding genetic and environmental affects on carcass composition in the pig. However, the major proportion of these studies relied on jointing carcasses into wholesale cuts ignoring the functional aspects of the tissues studied. Because of this, little opportunity was afforded to determine in detail changes in the proportions of tissues or their distribution within the carcass. In some cases the use of the jointing technique has resulted in quite inaccurate conclusions. For example, Cambridge studies proposed that a centripetal growth pattern existed beginning in the distal limbs and moving towards the loin which was classified as the latest developing region of the body. More recent growth studies based on complete anatomical dissection (Butterfield, 1963) have indicated that the loin really develops at the same relative rate as total muscle. The loin joint used by Hammond (1932)

contained a proportion of abdominal wall muscle which develops later than the loin. Including the abdominal muscle in the loin joint led to the conclusion that the loin was late developing.

As has been pointed out by Williams (1968a, b) the use of carcass joints in evaluating carcass composition is subject to error in reproducibility. In addition jointing provides only limited information of the growth and development of individual tissues. Because of this, two anatomical studies were undertaken in an attempt to further clarify the growth patterns of individual carcass tissues in the pig and to determine what affect various genetic and environmental factors might have on these patterns. Data from the first study have been presented in some detail already (Richmond and Berg, 1971a, b, c, 1972) and part of the data from Study 2 is presently being prepared for presentation (Lind et al, 1976; Wilson et al, 1976). A summary of the growth and carcass composition data for each study is presented in this chapter as a guide and reference point for the chapters on relative impetus of muscles and muscle chemical composition.

B) Materials and Methods

Study 1:

The methods, procedures and experimental design have been previously outlined (Skitsko, 1969; Skitsko and

Bowland, 1970) in reports concerning the nutritional aspects of the study. Basically the study involved 144 barrows and gilts of Duroc x Yorkshire (DY), Hampshire x Yorkshire (HY) and Yorkshire x Yorkshire (YY) breeding which were fed a standard early weaning ration containing 3500 kcal DE/kg and 20% crude protein from weaning at three weeks until they reached 23 kg liveweight. Thereafter they were individually fed either a high energy (HE) (3652 kcal DE/kg and 19.9% CP) or low energy (LE) (2757 kcal DE/kg and 15.3% CP) ration for two one-hour periods per day and slaughtered at either 68, 91 or 114 kg liveweight. A random sample of seventy-three pigs, representing breed, sex and ration treatments at each of the three slaughter weights were chosen for carcass dissection. An additional nine barrows and eight gilts of the same breed groups were slaughtered at 23 kg liveweight to establish a base for carcass composition comparisons. All slaughtering, carcass grading and Record of Performance measuring was done at a local packing plant. The left side of each carcass was returned to the University Meats Laboratory for dissection. Half carcasses were dissected into individual muscles, fat and bone (Butterfield and May, 1965). Fat was separated into subcutaneous (fat + skin), intermuscular and body cavity fat. Loose connective tissue was weighed with fat. Tendon was weighed separately but included with bone in this study.

Study 2:

Thirty-six barrows and 36 gilts of Yorkshire x Lacombe (YL) and Yorkshire x Lacombe-Yorkshire (YLY) breeding were fed a starter diet (ad libitum) until they exceeded 22.7 kg liveweight and thereafter were individually fed an experimental diet (2951 kcal/kg DE and 15.5% CP) at one of three feeding levels (3.2, 3.7 or 4.2% of body weight) and slaughtered at 68, 91 or 114 kg liveweight. Initially at the beginning of the experiment, feed levels of 3.0% and 4.0% of body weight and ad libitum were offered. However, it soon became obvious that the 3.0% feeding level was too low to maintain growth and this was raised to 3.5%. When individual feed intakes were calculated for the entire experiment, it was found that the actual realized levels of feeding were 3.2%, 3.7% and 4.2% corresponding to the nominal 3.5%, 4.0% and ad libitum feeding levels. All animals were weighed weekly and feeding levels adjusted accordingly.

All pigs were group housed in pens measuring 1.8 x 3.1 meters and were individually fed in stalls 0.45 meters wide. Those pigs receiving the 3.2% and 3.7% levels of feed were allowed equal portions of their daily allowance during two one-hour feeding periods (8 AM and 4 PM). Those pigs on the 4.2% level of feed were allowed an additional two hours of feeding time at 12 noon.

As in Study 1 all pigs were slaughtered at a local packing plant. However, unlike Study 1, the entire carcass was prepared at the Meats Laboratory. The head including jowls was removed at the atlanto-occipital joint and the carcass split with a handsaw. The right side of each carcass was divided into closely trimmed boneless retail cuts and the left side dissected into individual muscles and bone, skin, subcutaneous fat, intermuscular fat and body cavity fat as in Study 1. The only deviation in dissection procedure was the separation of skin from subcutaneous fat in Study 2. These tissues were removed together in Study 1. For the analysis of gross carcass composition in this chapter, fat is considered as weight of fat + skin for both studies.

Statistical analyses of the data involved multiway analyses of variance and mean comparisons (Steel and Torrie, 1960).

C) Results and Discussion

1. Tissue Growth

The average weight of the carcass and individual tissues (muscle, fat and bone) relative to liveweight for each study are plotted in Figure 1. Bone grew relatively slowly while muscle had a relatively high growth rate. Beyond 91 kg liveweight, muscle growth declined and fat deposition increased resulting in an almost linear increase

in carcass weight relative to liveweight. Fat comprised the greater proportion of the carcass weight increase beyond 91 kg liveweight. Similar tissue growth patterns have been observed in pigs by Cuthbertson and Pomeroy (1962) and Brooks et al (1964) and in cattle by Berg (1968) and Berg and Butterfield (1968).

2. Influence of Liveweight on Tissue Growth

Carcass composition and tissue growth data for Studies 1 and 2 are presented in Tables 1 and 2. Pigs in Study 2 were 19, 24 and 17 days older at 68, 91 and 114 kg liveweight respectively than pigs in Study 1 (Tables 1 and 2). However, carcass composition was similar for each group of pigs. Reid et al (1968) indicated that sheep restricted in feed intake were older but not different in carcass composition from those on normal feed intake when each were slaughtered at the same liveweight.

In each study, dressing percentage and back fat increased significantly ($P<0.05$) as liveweight increased. Carcass weight and the weight of muscle, fat and bone also increased significantly ($P<0.05$) with increasing liveweights. On a relative basis, however, percentage muscle and bone decreased and percentage fat increased ($P<0.05$) as liveweight increased. Between 23 and 114 kg liveweight carcass, muscle and fat growth per day of age increased while bone weight per day of age remained relatively

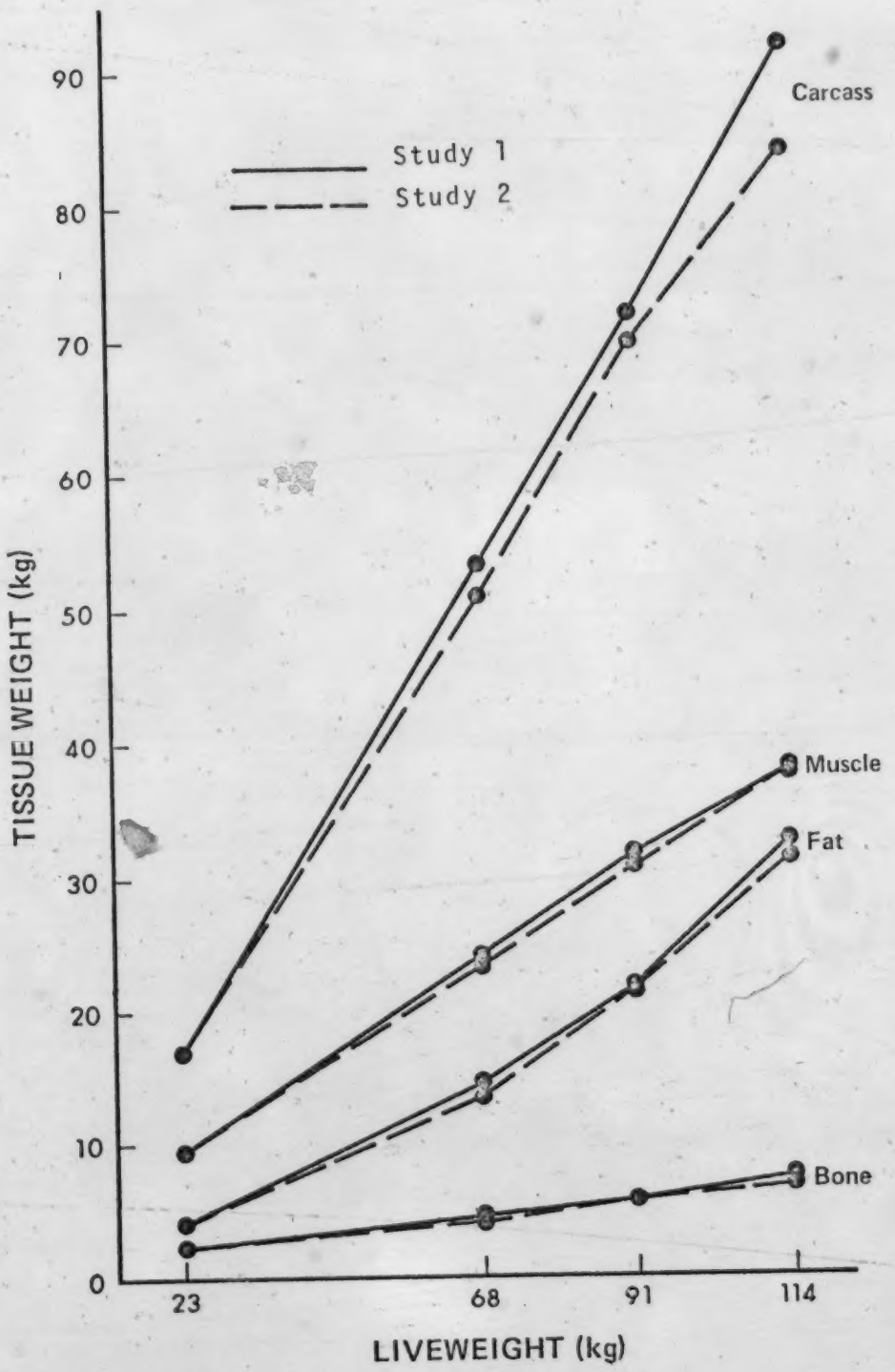

Figure 1. Carcass, muscle, fat and bone weights relative to liveweight in pigs (Studies 1 and 2).

TABLE 1. Influence of liveweight, breed, sex and ration on carcass composition and tissue growth in swine (Study 1)

	LIVE WEIGHT GROUP (kg)				BREED			SEX		RATION	
	23[1]	68	91	114	DY	HY	YY	Barrows	Gilts	LE	HE
No. of animals.....	17	24	24	25	23	23	27	37	36	35	38
Age at slaughter days..	75	149[a]	174[b]	211[c]	173[a]	173[a]	187[b]	176	180	191[a]	165[b]
Live weight.....kg	26.6	69.6[a]	91.9[b]	115.0[c]	92.2	92.4	92.0	92.5	91.8	92.1	92.3
Carcass weight.....kg	16.8	52.9[a]	71.5[b]	92.2[c]	73.0[a]	72.5[b]	71.1[c]	72.3	72.1	70.6[a]	73.8[b]
Dressing.....%	63.3	76.1[a]	77.8[b]	80.2[c]	78.8[a]	78.2[a]	77.0[b]	77.8	78.1	76.3[a]	79.7[b]
Total backfat[2].....cm	----	6.4[a]	7.3[b]	9.2[c]	7.9	7.3	7.8	8.1[a]	7.2[b]	7.1[a]	8.2[b]
Grade.....%	----	88[a]	103[b]	85[c]	91	92	92	91	92	92	92
CARCASS COMPOSITION											
Muscle.....kg	9.4	23.9[a]	31.7[b]	37.7[c]	30.7	32.2	30.4	29.6[a]	32.6[b]	32.3[a]	30.0[b]
Fat.....kg	4.1	14.6[a]	21.8[b]	32.8[c]	23.8	22.1	23.2	24.7[a]	21.4[b]	20.9[a]	25.1[b]
Bone.....kg	2.1	4.5[a]	5.6[b]	7.1[c]	5.7	5.8	5.9	5.6	6.0	5.9	5.8
Muscle.....%	60.4	55.7[a]	53.5[b]	48.7[c]	51.7	54.3	51.8	50.2[a]	55.0[b]	55.1[a]	50.1[b]
Fat.....%	25.9	33.8[a]	36.7[b]	42.1[c]	38.6	35.9	38.1	40.1[a]	34.9[b]	34.8[a]	40.3[b]
Bone.....%	13.2	10.5[a]	9.9[b]	9.2[c]	9.7	9.7	10.1	9.6	10.1	10.1	9.6
Muscle-bone ratio.....	4.6	5.3	5.4	5.3	5.4	5.6	5.1	5.3	5.5	5.5	5.2
GROWTH/DAY OF AGE											
Live.....g	354	473[a]	533[b]	550[c]	535[a]	532[a]	489[b]	529[a]	508[b]	478[a]	559[b]
Carcass.....g	275	361[a]	415[b]	441[c]	425[a]	416[a]	377[b]	413[a]	398[b]	366[a]	448[b]
Muscle.....g	118	163[a]	183[b]	179[c]	177[a]	185[b]	161[c]	170[a]	180[b]	167[a]	182[b]
Fat.....g	54	99[a]	126[b]	157[c]	136[a]	126[b]	121[c]	139[a]	116[b]	106[a]	149[b]
Bone.....g	27	31	34	34	33	33	32	32	33	30[a]	35[b]
Feed conversion kg/kg..	.89	3.01	3.06	3.38	3.15	3.04	3.26	3.19	3.11	3.58[a]	2.72[b]

[1] Means for pigs slaughtered at 23 kg not included in statistical comparisons.

[2] Total of 3 measurements.

a, b, c, means within the same classification having different superscripts, differ significantly at $P<0.05$ or $P<0.01$

Table 2. Influence of liveweight, breed, sex and feedling level on carcass composition and tissue growth in swine (Study 2).

	Liveweight (kg)					Breed			Sex			Feeding Level			
	23*	68	91	114	SE	YL	YLY	SE	Barrow	Gilt	SE	3.2%	3.7%	4.2%	SE
No. of animals.....	17	24	24	24		36	36		36	36		24	24	24	
Age at slaughter.....	75	168[a]	198[b]	228[c]	3.47	198	198	2.84	201	195	2.84	232[a]	188[b]	174[c]	3.47
Slaughter weight.....kg	26.6	68.71[a]	91.48[b]	114.10[c]	0.44	91.07[a]	91.79[b]	0.36	90.93	91.92	0.36	91.23	91.63	91.42	0.44
Carcass weight.....kg	16.8	50.51[a]	69.34[b]	88.32[c]	0.48	68.85[a]	69.97[b]	0.39	69.45	69.36	0.39	68.67[a]	69.16[ab]	70.39[b]	0.48
Dressing.....%	63.3	73.51[a]	75.85[b]	77.41[c]	0.36	75.30	75.87	0.30	76.01[a]	75.16[b]	0.30	75.06[a]	75.18[a]	76.52[b]	0.36
Total backfat.....cm	----	6.70[a]	8.19[b]	9.61[c]	0.20	8.30	8.04	0.16	8.60[a]	7.73[b]	0.16	7.31[a]	8.19[b]	8.99[c]	0.20
Grade.....%	----	88	105	89	0.97	94	95	0.79	93	95	0.79	95	94	93	0.97
CARCASS COMPOSITION															
Muscle.....kg	9.40	23.20[a]	30.53[b]	37.29[c]	0.38	29.74[a]	30.94[b]	0.37	29.52[a]	31.16[b]	0.37	31.32[a]	29.84[b]	29.87[b]	0.38
Fat.....kg	4.10	13.77[a]	21.39[b]	31.24[c]	0.58	22.25	22.02	0.47	23.35[a]	20.92[b]	0.47	20.54[a]	21.98[a]	23.88[b]	0.58
Bone.....kg	2.10	4.26[a]	5.73[b]	6.81[c]	0.09	5.53	5.66	0.08	5.50[a]	5.69[b]	0.08	5.78[a]	5.53[b]	5.47[b]	0.09
Muscle.....%	60.40	56.36[a]	53.07[b]	49.58[c]	0.64	52.46	53.54	0.52	51.29[a]	54.71[b]	0.52	55.05[a]	52.66[b]	51.30[b]	0.64
Fat.....%	25.90	33.29[a]	36.99[b]	41.37[c]	0.69	37.76	36.66	0.57	39.13[a]	35.30[b]	0.57	34.73[a]	37.57[b]	39.34[b]	0.69
Bone.....%	13.20	10.35[a]	9.95[a]	9.06[b]	0.18	9.78	9.79	0.15	9.58	9.99	0.15	10.22[a]	9.77[b]	9.36[b]	0.18
Muscle/bone ratio.....	4.6	5.46	5.37	5.50	0.34	5.42	5.48	0.27	5.40	5.49	0.27	5.43	5.40	5.51	0.34
GROWTH/DAY OF AGE															
Live.....g	354	419[a]	475[b]	508[c]	8.65	467	467	7.06	460	475	7.06	392[a]	487[b]	523[c]	8.65
Carcass.....g	275	308[a]	360[b]	394[c]	6.71	352	355	5.48	351	357[b]	5.48	295[a]	366[b]	401[c]	6.71
Muscle.....g	118	141[a]	158[b]	165[b]	3.17	152	158	2.69	149[a]	161[b]	2.69	135[a]	158[b]	171[c]	3.17
Fat.....g	54	84[a]	111[b]	140[c]	3.34	113	111	2.73	117[a]	106[b]	2.73	87[a]	114[b]	134[c]	3.34
Bone.....g	27	26[a]	30	30[b]	0.74	28	29	0.60	28	29	0.60	31[a]	29[a]	25[b]	0.74
Feed conversion....kg/kg	0.89	3.32[a]	3.57[b]	3.94[c]	0.08	3.63	3.59	0.06	3.74[a]	3.48[b]	0.06	3.91[a]	3.43[b]	3.50[b]	0.08

*Means for pigs slaughtered at 23 kg not included in statistical comparisons.
2=Total of three measurements.
a, b, c, means within the same classification followed by different letters differ significantly at $P<0.05$ or $P<0.01$.

constant. Because of the difference in age of the pigs in each study, growth per day of age was somewhat greater for each measurement in Study 1 than in Study 2. However, muscle and fat were being deposited at similar relative rates in each study. The ratios of muscle per day of age to fat per day of age were 1.64, 1.45 and 1.14 in Study 1 and 1.67, 1.42 and 1.17 for pigs in Study 2 at 68, 91 and 114 kg liveweight respectively. As liveweight increased, the rate of fat deposition increased and muscle growth decreased. At 91 kg liveweight pigs in Study 1 had 84% of the muscle and 66% of the fat that was present at 114 kg liveweight. Corresponding figures for pigs in Study 2 were 82% of muscle and 68% of fat.

Feed conversion remained relatively constant as liveweight increased in Study 1 but in Study 2 feed conversion increased significantly ($P<0.05$) as liveweight increased. The lower nutrient density of the Study 2 ration may have necessitated a higher intake to meet energy requirements.

3. Influence of Breed on Tissue Growth

Comparisons among breed groups are presented but cannot be considered as being specific for the breed groups studied. In Study 1, HY and DY pigs were crossbreds while YY pigs were purebreds. In Study 2, YL pigs were first cross progeny while YLY pigs were backcross progeny. Gain and

carcass traits may have been influenced by heterosis and its importance could not be assessed in these studies.

In Study 1 there were no significant differences in the weights or percentages of total muscle, fat or bone among breed groups. HY pigs did however tend to have slightly more muscle and less fat than DY or YY pigs. In Study 2, YLY pigs had slightly more muscle and less fat ($P<0.05$) than YL pigs but on a relative basis there were no significant differences between breed groups in percentage muscle, bone or fat.

YY pigs in Study 1 were 14 days older than DY or HY pigs and therefore had the lower carcass and tissue growth rates per day of age. Of the three breed groups HY pigs had the greater muscle per day of age and DY pigs the greater fat per day of age. Carcass growth per day of age was similar for DY and HY pigs. In Study 2 carcass and tissue growth per day of age were similar for the two breed groups. These data indicated that breed groups were similar in feed conversion in each study. However, the 73 pigs dissected in Study 1 were only a sample of the 144 pigs making up the experiment. Skitsko and Bowland (1970) indicated that, when considering the entire group, HY and YY pigs were more efficient in feed conversion than DY pigs.

4. Influence of Sex on Tissue Growth

In each study gilts had less ($P<0.05$) backfat, carcass fat and percentage of fat and more ($P<0.05$) muscle and percentage muscle than did barrows (Tables 1 and 2). Muscle-bone ratio and bone weight were similar for each sex. In Study 1 liveweight, carcass weight and fat weight per day of age was less and muscle weight per day of age greater for gilts than for barrows. In Study 2, liveweight and carcass weight per day of age were similar between sexes but muscle weight per day of age was greater and fat weight per day of age was less for gilts as compared to barrows ($P<0.05$).

Differences in feed conversion for the 73 pigs dissected in Study 1 were not significant but data for the entire experiment (Skitsko and Bowland, 1970) indicated that gilts required less feed/kg gain than did barrows. In Study 2, gilts consumed significantly less ($P<0.05$) feed/kg gain than barrows (3.48 vs 3.74).

5. Influence of Ration and Feeding Level on Tissue

In Study 1 differences in carcass composition due to ration groups were similar to differences due to sex. Pigs fed the HE ration corresponded to barrows and those fed the LE ration corresponded to gilts (Table 1).

LE fed pigs had greater weights and percentages of muscle and smaller weights and percentages of fat ($P<0.05$)

compared to HE fed pigs. Because they were older (26 days) LE fed pigs had smaller liveweight, carcass weight and tissue weight gains per day of age than the HE fed pigs. Feed conversion favored the HE over the LE fed pigs (2.72 vs. 3.58).

In Study 2 pigs fed at the 3.2% level were similar in carcass weight and dressing percentage to those fed at the 3.7% level. Pigs fed at the 4.2% level exceeded those at the 3.2% and 3.7% levels in each of these measurements ($P<0.05$). Pigs fed at the 3.2% level had greater weights and percentages of muscle and bone and smaller weights and percentages of fat ($P<0.05$) than those fed at the 3.7% or 4.2% levels which were similar. Because of the significant difference in ages (232, 188 and 174 days for pigs fed at the 3.2, 3.7 and 4.2% levels respectively), pigs fed at the 4.2% level of feeding had the largest and those fed at the 3.2% level the smallest liveweight, carcass weight and tissue weight gains per day of age ($P<0.05$). Pigs fed at the 3.7% level of feeding were intermediate in daily weight gains.

Feed conversion ratios were greater for those pigs fed at the 3.2% level of feeding than for those at the 3.7% and 4.2% feeding levels which had similar ratios.

6. Interaction Effects on Tissue Growth

Interactions, significant at either the 5% or 1% level among liveweight, breed, sex and ration observed in Study 1 are presented in Tables 3 to 7.

Table 3 presents the interaction of live slaughter weight by sex and live slaughter weight by ration on carcass grade indexes. At 91 kg liveweight gilts were superior to barrows in grade indexes (105 vs. 102) and pigs fed the LE ration were superior to those fed the HE ration while carcass grade indexes for pigs slaughtered at 68 kg and 114 kg did not reflect carcass composition differences. This may be due to the insensitivity in the grading system at the light and heavy weights.

On the LE ration both barrows and gilts reached slaughter weight at similar ages (192 and 190 days respectively) while on the HE ration barrows reached market 11 days earlier than gilts (159 vs. 170 days respectively) (Table 4).

Gilts on the LE ration had more muscle per day of age, a greater final weight and slightly greater carcass weight per day of age than did barrows. On the other hand, barrows on the HE ration were equal to gilts in muscle per day of age but had a greater final weight and carcass weight per day of age than did gilts (Tables 4, 5, 6).

Each of these sex by ration effects on carcass

Table 3. Mean carcass grade indexes (%) as influenced by interactions of slaughter weight by sex and slaughter weight by ration (Study 1).

Slaughter weight	SEX		RATION	
	Barrows	Gilts	LE	HE
68	89	87	87	89
91	102	105	105	102
114	84	86	86	84

Table 4. Slaughter age (days) and muscle per day of age (g) as influenced by interaction of sex by ration (Study 1).

Characteristic	Sex	RATION	
		LE	HE
Slaughter age (days)	Barrows	192	159
	Gilts	190	170
Muscle per day of age (g)	Barrows	159	182
	Gilts	182	182

Table 5. Final weight per day of age (g) as influenced by breed by sex and ration by sex interactions (Study 1).

Sex	BREED			RATION	
	DY	HY	YY	LE	HE
Barrows	533	561	494	475	584
Gilts	536	503	483	481	534

Table 6. Carcass weight per day of age (g) as influenced by breed by ration and sex by ration interactions (Study 1).

Ration	BREED			SEX	
	DY	HY	YY	Barrows	Gilts
LE	371	379	346	363	369
HE	474	454	409	464	428

Table 7. Fat per day of age (g) as influenced by breed by sex interaction (Study 1).

Sex	BREED		
	DY	HY	YY
Barrows	147	145	125
Gilts	124	107	117

composition were a reflection of the sex by ration interactions for feed conversion reported by Skitsko and Bowland (1970). Barrows on the LE ration had less efficient feed conversion than gilts but were equal to gilts on the HE ration.

In all three breed groups those pigs fed the HE ration had a greater carcass weight per day of age than those fed the LE ration. However, breed groups ranked differently on the rations (Table 6). On the LE ration, HY pigs had the greater carcass weight per day of age followed by DY and YY pigs. On the HE ration DY pigs were followed by HY and then YY pigs.

As with the barrow-gilt comparisons, pigs with an inherent predisposition to lean growth grew faster on the LE ration while pigs with a predisposition to fatten appeared to grow faster on the HE ration.

In the breed by sex interaction (Table 7) gilts from each breed had less fat per day of age than did barrows but breed group ranking differed with the sex of pig compared. DY barrows had similar fat per day of age to HY barrows and both groups had more fat per day of age than YY barrows. HY gilts had the least fat per day of age followed by YY and DY gilts.

In Study 2 interactions were observed between breed and

Table 8. Breed by feed level interaction on fat per day of age (g) (Study 2).

Breed	FEED LEVEL		
	3.2%	3.7%	4.2%
YL	86	120	146
YLY	88	108	122

Table 9. Sex by breed interaction affect on feed conversion ratio (Study 2).

Breed	SEX	
	Barrow	Gilt
YL	3.87	3.39
YLY	3.61	3.57

level of feeding for fat gain/day of age (Table 8) and between sex and breed for feed conversion (Table 9). At the 3.2% level of feeding YL and YLY pigs were similar in fat gain/day of age but as the feeding level increased to 3.7 and 4.2%, YL pigs appeared to deposit more fat per day than the YLY pigs.

Although there were no differences noted between breed groups in feed conversion (Table 1), YL barrows appeared to be less efficient in feed conversion than YLY barrows but YL gilts were more efficient than YLY gilts (Table 9).

7. Considerations in Pork Production

From these data it would appear that carcass composition may be altered by the influence of breed, sex and ration. Gilts, pigs fed LE rations or restricted in feeding, or strains of pigs with a predisposition to lean growth may be fed to heavier liveweights than are presently accepted. Under the present grading system, carcasses from pigs outside a range of 75 to 100 kg liveweight are penalized. There are several reports which suggest that pigs slaughtered at both 68 and 114 kg liveweight can be produced and processed efficiently and economically and still meet consumer desires (Bellis and Taylor, 1961; Brooks et al., 1964; Field et al., 1961; Varney et al., 1962). Bellis and Taylor (1961) indicated the cost of lean production in the carcass is highest at 90 - 140 pounds (41-64 kg) liveweight

and decreases as liveweight increases. From this data costs per pound of lean were similar for pigs slaughtered between 220 and 300 pounds (100-136 kg) liveweight. Berg and Richmond (1969) suggested that costs per unit of muscle were not markedly different for pigs slaughtered at either 68, 91 or 114 kg liveweight. The data of Doornenbal (1971, 1972) would indicate that the relative changes in the rate of muscle and fat deposition in pigs up to 132 kg liveweight are not dramatic enough to warrant automatic dismissal to lower grades. Results from the studies reported here would tend to support these findings. Even though the rate of fat deposition increased and that of muscle decreased most markedly beyond 91 kg liveweight, muscle still made up a greater proportion of the carcass than did fat at 114 kg liveweight.

In North America, the variety of pork products is restricted to five or six primal cuts from pigs weighing an average of 90 kg liveweight. Little effort has been extended to evaluate products that might ensue from pigs of lighter or heavier weights. Such evaluations might have a direct effect on pig production. For example, pigs with a predisposition to fat growth might be marketed at lighter weights while pigs with a predisposition to muscle growth might be marketed at heavier weights. In these studies, gilts slaughtered at 114 kg liveweight had similar

proportions of muscle and fat in the carcasses as barrows slaughtered at 91 kg liveweight (Table 10). If gilts could be slaughtered at heavier weights without penalty, the producer might be afforded the opportunity for a more critical herd selection. Barren gilts and others selected for breeding but found unsuitable for some reason could still be marketed under a carcass merit assessment. At the moment, breeding gilts must be selected prior to 90 kg liveweight and no compensation is provided the producer for those that are subsequently culled and marketed regardless of their carcass composition. Marketing gilts at heavier weights may not improve the genetic composition of the herd appreciably but it may afford the producer additional income to offset increasing operating costs. In addition, if carcasses exceeding 100 kg liveweight are presently processed into products other than chops, roasts, bacon, etc. (which may be questionable) the supply of these products might be increased.

Diminishing supplies and increasing costs of available feed stuffs for pigs may well dictate slaughter weights and subsequent pork products in the future. If one assumes that pigs may have to be fed lower energy and more fibrous rations in the future then it might be expected that the length of feeding time may be longer and carcass weights heavier to achieve similar relative proportions of muscle

Table 10. Relative proportions of muscle and fat in barrow and gilt carcasses at different liveweights (Study 1 and 2).

	Liveweight (kg)					
	68		91		114	
Sex:	Barrow	Gilt	Barrow	Gilt	Barrow	Gilt
Study 1						
% Muscle	54	58	51	56	46	52
% Fat	35	32	39	34	45	38
Study 2						
% Muscle	54	59	52	54	48	51
% Fat	36	30	38	36	43	39

and fat considered acceptable today. On the other hand, the costs of production might change under such a system to warrant the marketing of lighter weight pigs. In anticipation of future production requirements effort should be extended now to properly evaluate the carcass merit of pigs slaughtered outside the present mandatory range of liveweights.

II. Relative Growth Patterns and Distribution of Muscle

A) Introduction

As an animal increases in liveweight from birth to maturity, major tissues within the body undergo differential development and weight distribution. Those tissues whose growth is governed mainly by functional demands exhibit an early stage of differentiation. Muscle is one of these, as well as being the most economically important tissue in the carcass. Early evaluations of muscle content and distribution were conducted by jointing the carcass into "butchers' cuts". In most instances, separations by this technique did not follow precise anatomical and functional divisions of muscles and led to the assumption that genetic or environmental factors might influence the distribution of muscle within the carcass. More recent evaluations based on the technique of serial slaughter and anatomical dissection have assisted in a better understanding of the functional aspects of muscle development and its response to genetic and environmental effects (Berg, 1967; Butterfield, 1963, 1966; Butterfield and Berg, 1966, a, b, c; Butterfield and Johnson, 1971; Davies, 1974; Lohse, 1973; Mukhoty and Berg, 1973; Richmond and Berg, 1971, b).

Muscle growth and distribution in swine as influenced by liveweight, breed, sex and ration was reported by Richmond and Berg (1971 b). In that study, it was found that

most differentiation in growth and distribution of standard muscle groups had occurred at or before 23 kg liveweight and thereafter their proportions remained relatively constant up to 114 kg liveweight. Differences in muscle distribution due to the influence of breed, sex or ration were minor. However, because of the influence that individual muscles may have on muscle groups, it appeared necessary to analyse the relative growth patterns of individual muscles and muscle groups over a number of liveweights and for different breeds, sexes and rations.

The present chapter reports the results from two studies of muscle-weight distribution and the relative percentages and allometric growth patterns of individual muscles and muscle groups in swine.

B) Materials and Methods

The design and allotment of animals for each study has been previously presented (pages 6 and 7). However, the muscle data reported here for Study 1 includes an additional 19 HY barrows and gilts which were slaughtered at the same liveweights but were fed the HE and LE rations on an ad libitum basis rather than at two one-hour intervals. A multiway analysis of variance indicated that there were no significant differences in muscle growth or distribution between the ad libitum and hourly-fed HY pigs. Data from the 23 kg liveweight group slaughtered in Study 1 are not

included in the statistical analyses but are included in the tables for each study as reference points.

Half-carcasses were dissected into individual muscles, fat and bone using the technique of Butterfield and May (1965). Minor differences in carcass preparation were employed between the two studies. In Study 1 half-carcasses were prepared at a local abattoir and delivered to the meats laboratory for dissection. In Study 2 the entire carcass was delivered to the meats laboratory where the head was removed and the carcass halved. Skin, subcutaneous fat and M. cutaneous trunci were removed together and then separated in Study 2 while in Study 1 subcutaneous fat and skin and M. cutaneous trunci were individually dissected directly from the half-carcass. When necessary for comparison, individual muscles were grouped into nine "standard muscle groups" and "three expensive groups" (Tables 11 and 14).

Growth coefficients for individual muscles and muscle groups were calculated by the allometric equation $Y=ax$, described by Huxley (1932), and which is equivalent to log $Y=a+b$ log X where "Y" represents individual muscles or muscle groups, "X" represents total muscle, "b" represents the growth coefficient and "a" represents the intercept of the ordinate. This allometric equation has previously been used to calculate growth coefficients for both physical components of the carcass (Butterfield and Berg, 1966a, b,

c; Davies, 1974; Elsley et al, 1964; Lohse et al, 1971) and chemical carcass components (Suess et al, 1969).

Multiway analysis of variance, regression and comparisons of means were carried out according to methods outlined by Steel and Torrie (1960).

C) Results

Muscle distribution data from the first study has been presented previously (Richmond and Berg, 1971b) and is summarized here for convenient reference. In Study 1 muscle distribution was affected only slightly by the influence of liveweight, breed, sex or ration (Table 11). Pigs slaughtered at 91 kg liveweight appeared to have a significantly greater percentage of muscle in muscle group 9 (neck and thorax) than those slaughtered at 68 kg liveweight. DY pigs had a greater percentage ($P<0.05$) of spinal muscle than either HY pigs or YY pigs. At 23 kg liveweight, gilts had a greater percentage of muscle in the proximal pelvic limb, spinal and expensive muscle groups and a smaller percentage of muscle in the neck and thorax (Table 12). At heavier liveweights, these differences disappeared with gilts exceeding barrows only in percentage muscle in the distal thoracic limb, while barrows exceeded gilts in percent spinal muscle. Two minor interactions between sex and ration, and sex and breed, were observed for muscle group 7 (thorax to thoracic limb) (Table 13). On the LE

Table 11. "Standard muscle groups" as percentages of weight of total side muscle in barrows and gilts of three breeds fed low and high energy rations and slaughtered at four live weights.

	LIVE WEIGHT (kg)				BREED			SEX		RATION	
	23 (1)	68	91	114	DY	HY	YY	Barrows	Gilts	LE	HE
No. of animals	17	30	30	32	23	42	27	46	46	46	46
MUSCLE GROUP											
1. Proximal pelvic limb	26.56	28.40	28.25	28.67	28.39	28.42	28.50	28.67	28.71	28.42	28.46
2. Distal pelvic limb	3.99	3.96	3.84	3.87	3.86	3.84	3.97	3.84	3.95	3.81^{a}	3.98^{b}
3. Spinal	16.83	17.01	17.42	17.44	17.69^{a}	17.17^{ab}	17.01^{b}	17.54^{a}	17.05^{b}	17.32	17.26
4. Abdominal	12.41	11.32	10.98	11.16	11.16	11.21	11.10	11.22	11.09	11.05	11.26
5. Proximal thoracic limb	12.35	12.29	12.05	11.79	11.87	11.94	12.32	11.90	12.18	12.08	12.00
6. Distal thoracic limb	2.15	1.94	1.89	1.85	1.88	1.89	1.91	1.84^{a}	1.95^{b}	1.89	1.90
7. Thorax to thoracic limb	7.35	7.56	7.64	7.38	7.42	7.57	7.58	7.48	7.57	7.48	7.57
8. Neck to thoracic limb	4.39	4.90	4.84	4.97	4.88	4.91	4.92	4.77	5.03	4.94	4.87
9. Neck and thorax	9.28	9.39^{a}	10.02^{b}	9.76^{ab}	9.66	9.81	9.69	9.66	9.78	9.85	9.60
10. Scrap	4.69	3.21	3.06	3.08	3.15	3.20	3.01	3.07	3.17	3.15	3.09
Expensive groups:											
A	30.61	32.36	32.09	32.54	32.25	32.27	32.48	32.50	32.16	32.23	32.43
B	47.46	49.38	49.51	49.98	49.95	49.44	49.48	50.04^{a}	49.20^{b}	49.55	49.70
C	59.81	61.67	61.56	61.78	61.82	61.38	61.80	61.94	61.39	61.63	61.70

A (Group 1 + Group 2).
B (Group 1 + Group 2 + Group 3).
C (Group 1 + Group 2 + Group 3 + Group 5).
a, b, c, means within the same classification having different superscripts, differ significantly at $P<0.05$.
(1) 23 kg group not tested statistically against other weight groups.

Table 12. Muscle group percentages differing significantly between barrows and gilts slaughtered at 23 kg liveweight (Study 1).

Muscle Groups	Barrows	Gilts
1) Proximal pelvic limb	25.56	27.68**
3) Spinal	16.46	17.24*
9) Neck and thorax	9.87*	8.62
Expensive Groups:		
A	29.56	31.66**
B	46.02	48.98**
C	58.37	61.24**

*Significant at $P<0.05$, **significant at $P<0.01$.

ration, barrows had a greater percentage of muscle from thorax to thoracic limb than did gilts, while gilts had a greater percentage of muscle in this group on the HE ration. DY barrows had a greater percentage of muscle in muscle group 7 than did gilts, while the reverse of this was true for the HY and YY barrows and gilts. No explanation for these interactions was apparent at the time but may be explained by the data in this paper.

In the second study, different breeds and feeding levels, more limiting to growth were used. The results are presented in Table 14. As in the first study, liveweight had little influence on muscle distribution within the carcass. Only the distal limb muscle groups were found to differ significantly. Pigs slaughtered at 68 and 91 kg liveweight had a greater percentage of muscle in the distal pelvic limb than those slaughtered at 114 kg liveweight (4.17 and 4.08% vs. 3.82% respectively). These differences were reflected in expensive muscle group "A" with pigs slaughtered at 68 and 91 kg having a greater percentage of muscle in this group than those slaughtered at 114 kg liveweight (33.57 and 33.72% vs. 32.84% respectively). Pigs slaughtered at 68 kg liveweight had a greater percentage of muscle in the distal thoracic limb than those slaughtered at 91 and 114 kg liveweight (2.05% vs. 1.96 and 1.94% respectively).

Breed differences were observed in three muscle groups.

Table 13. Percentages in muscle group 7 (thorax to thoracic limb) showing interactions of sex by ration and sex by breed ($P < 0.05$) (Study 1).

Sex	RATION		BREED		
	LE	HE	DY	HY	YY
Barrows	7.52	7.44	7.65	7.43	7.37
Gilts	7.44	7.70	7.20	7.72	7.79

Table 14. Standard muscle groups as a percentage of weights of total side muscle in barrows and gilts of two breed groups fed at three levels and slaughtered at three liveweights (Study 2).

	LIVEWEIGHT (kg)					BREED			SEX			FEED LEVEL			
	23*	68	91	114	SE	YL	YLY	SE	Barrow	Gilt	SE	3.2%	3.7%	4.2%	SE
No. of animals	17	24	24	24		36	36		36	36		24	24	24	
MUSCLE GROUP															
1. Proximal pelvic limb	26.56	29.40	29.64	29.02	.217	29.50	29.20	.177	29.48	29.22	.177	29.46	29.29	29.31	.217
2. Distal pelvic limb	3.99	4.17^{A}	4.08^{A}	3.82^{B}	.042	4.05	4.00	.035	4.09^{a}	3.96^{b}	.035	3.94	4.07	4.06	.042
3. Spinal	16.83	16.86	17.04	17.09	.184	16.69^{a}	17.30^{b}	.150	16.90	17.09	.150	17.02	16.85	17.12	.184
4. Abdominal	12.41	10.17	10.12	10.04	.100	10.27^{a}	9.96^{b}	.082	10.11	10.11	.082	9.73^{A}	10.36^{B}	10.24^{B}	.100
5. Proximal thoracic limb	12.35	11.98	12.22	12.36	.116	12.17	12.20	.094	12.14	12.13	.094	12.29	12.22	12.05	.116
6. Distal thoracic limb	2.15	2.05^{A}	1.96^{B}	1.94^{B}	.020	1.94^{A}	2.02^{B}	.017	1.98	1.99	.017	2.00	1.98	1.97	.020
7. Thorax to thoracic limb	7.35	6.98	7.08	7.20	.077	7.09	7.08	.063	7.05	7.13	.063	7.06	7.21	6.98	.077
8. Neck to thoracic limb	4.39	4.62	4.73	4.81	.062	4.76	4.67	.051	4.71	4.73	.051	4.67	4.75	4.74	.062
9. Neck and thorax	9.28	8.98	8.95	9.20	.209	9.01	9.07	.096	9.04	9.04	.096	9.15	8.98	9.00	.209
10. Scrap	4.69	5.04	4.26	4.52	.220	4.62	4.59	.180	4.63	4.58	.220	4.72	4.42	4.68	.180
EXPENSIVE GROUPS:															
A	30.61	33.57^{A}	33.72^{A}	32.84^{B}	.232	33.55	33.20	.190	33.57	33.18	.190	33.40	33.36	33.37	.232
B	47.46	50.43	50.76	49.93	.269	50.25	50.50	.219	50.47	50.28	.219	50.42	50.21	50.50	.269
C	59.81	62.41	62.97	62.29	.250	62.42	62.70	.204	62.61	62.51	.204	62.71	62.42	62.55	.250

*23 kg group (from Study 1) not tested statistically against other weight groups.
A (Group 1 + 2); B (Group 1 + Group 2 + Group 3); C (Group 1 + Group 2 + Group 3 + Group 5).
a, b, c, and A, B, C, means within the same classification followed by different letters differ significantly at $P<0.05$ and $P<0.01$ respectively.

YLY pigs had a greater percentage than YL pigs in muscles of the spinal region (17.30 vs 16.69%) and of the distal thoracic limb (2.02 vs 1.94%) and a smaller percentage of muscle in the abdominal muscle group (9.96 vs 10.23%) ($P<0.05$, 0.01) (Table 14).

Sex affected the muscles of the distal pelvic limb with barrows having a greater ($P<0.05$) percentage of muscle than gilts (4.09 vs 3.96%) in this group.

Pigs fed at the 3.2% level had a smaller ($P<0.05$) percentage of muscle in the abdominal group than those fed at the 3.7% or 4.2% levels (9.73 vs 10.36 and 10.24% respectively).

Significant interactions ($P<0.05$) were observed for weight x feeding level, breed x feeding level and weight x breed effects. The proximal and distal pelvic limb and abdominal muscle groups were each affected by weight x feeding level (Table 15). As liveweight increased from 68 to 114 kg, percentage muscle of the proximal pelvic limb in those pigs fed at the 3.2% level decreased, but increased slightly, in those pigs fed at the 4.2% level and remained relatively constant at each liveweight for those pigs fed at the 3.7% level.

Percentage muscle in the distal pelvic limb decreased as liveweight increased within each feeding level. Pigs fed

Table 15. Weight by feeding level interaction on percentage muscle in three muscle groups (Study 2).

Muscle Group	Proximal Pelvic Limb			Distal Pelvic Limb			Abdominal		
Liveweight (kg)	68	91	114	68	91	114	68	91	114
Feed Level 3.2%	29.86	30.18	28.33	4.11	3.98	3.74	9.48	9.74	9.97
3.7%	29.39	28.99	29.49	4.22	4.25	3.73	10.50	10.50	10.07
4.2%	28.95	29.75	29.24	4.18	4.01	4.00	10.53	10.11	10.09

at the 3.7% level had the largest percentage of muscle in this group at 91 kg liveweight while pigs fed the 4.2% level had the largest percentage of muscle at 114 kg liveweight.

As liveweight increased from 68 to 114 kg, percentage muscle in the abdominal muscle group increased from 9.48 to 9.97% in those pigs fed at the 3.2% level but decreased from 10.50 to 10.07% and 10.53 to 10.09% in those pigs fed at the 3.7% and 4.2% levels respectively. At 68 and 91 kg liveweight, pigs fed the 3.2% level had a smaller percentage of muscle in this group than those fed at the 3.7% and 4.2% levels but at 114 kg liveweight these differences essentially disappeared (Table 15).

Interactions between breed and feeding level were observed for the proximal pelvic limb and expensive muscle group "A" (proximal and distal pelvic limb) (Table 16). Within each breed group percentage muscle in the proximal pelvic limb was slightly higher for those pigs on the 3.2% and 3.7% feeding levels than for those on the 4.2% level of feeding. At each feeding level, YL pigs had a slightly greater percentage of muscle in this group than did the YLY pigs. For expensive muscle group "A", the two breed groups were similar in percentage muscle at the 3.2% and 4.2% levels of feeding but at the 3.7% feeding level the YL pigs had a greater percentage of muscle in this group than did the YLY pigs (34.08 vs 32.64%). However, these differences

Table 16. Breed by feeding level interaction on percentage muscle in two muscle groups (Study 2) ($P<0.05$).

Muscle Group		Proximal Pelvic Limb			Expensive Muscle Group A		
Feed Level		3.2%	3.7%	4.2%	3.2%	3.7%	4.2%
Breed	YL	29.61	29.73	29.16	33.27	34.08	33.31
	YLY	29.19	29.55	28.87	33.53	32.64	33.44

may be more a result of sampling than breed x feed level effects.

Weight x breed interactions are presented in Table 17. At 114 kg liveweight, YL pigs had a greater percentage of abdominal muscle and a smaller percentage of muscle in the distal thoracic limb than YLY pigs.

Evaluation of muscle growth was extended to include comparative growth patterns of individual muscles. Table 18 presents the weight of individual muscles as a percentage of total muscle weight at each of four liveweights. Both Studies 1 and 2 are included. As seen from the table, the majority of individual muscles in the carcasses studied weighed less than 1% of total muscle. Of the 96 muscles dissected, 22 weighed from 1 to 3%, five weighed from 3 to 7% and one weighed from 10 to 12% of total muscle. The remaining 69 muscles each weighed less than 1% of total muscle. Small but consistant differences in muscle percentages between Studies 1 and 2 were observed.

Some of these percentage differences may have been due to slight differences between studies in the separation of small or closely attached muscles. As well, some differences may have been the result of carcass preparation. Carcasses from the second study which were prepared at the meats laboratory had 4.6% scrap muscle compared to 3.1% scrap

Table 17. Weight by breed interaction on percentage muscle in two muscle groups (Study 2) ($P<0.05$).

Muscle Group		Abdominal			Distal Thoracic Limb		
Liveweight (kg)		68	91	114	68	91	114
Breed	YL	10.27	10.06	10.47	2.02	1.96	1.86
	YLY	10.07	10.18	9.62	2.08	1.97	2.02

Table 18. Individual muscle weights and standard errors as a percent of total muscle at each of four liveweights (Studies 1 and 2).

Study			1		2		1		2		1		2	
Liveweight (kg)	23*		68		68		91		91		114		114	
Muscle	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE
No. of animals	17		30		24		30		24		32		24	
MUSCLE GROUP 1														
Proximal Pelvic Limb														
M. Tensor Fasciae Latae	.73	.08	.84	.09	.88	.09	.87	.11	.89	.13	.85	.09	.87	.11
M. Biceps Femoris	6.09	.41	6.74	.44	6.94	.32	6.73	.39	6.98	.39	6.82	.48	6.97	.40
M. Glutaeus Medius	3.33	.28	3.49	.27	3.79	.27	3.46	.30	3.78	.23	3.57	.25	3.55	.22
M. Vastus Lateralis	1.53	.14	1.59	.14	1.68	.09	1.59	.10	1.73	.15	1.60	.13	1.65	.11
M. Glutaeus Accessorius	.80	.12	.88	.09	.85	.07	.85	.12	.84	.05	.83	.11	.80	.08
M. Glutaeus Profundus	.38	.05	.40	.08	.42	.03	.42	.11	.42	.05	.43	.14	.40	.05
M. Rectus Femoris	1.92	.37	1.98	.19	2.11	.13	1.94	.22	2.14	.14	1.95	.12	2.11	.13
M. Semitendinosus	1.91	.52	2.17	.16	2.21	.16	2.12	.22	2.25	.18	2.16	.21	2.25	.20
M. Gracilis	.94	.10	1.00	.11	.99	.09	.99	.11	.99	.09	1.03	.07	1.00	.09
M. Semimembranosus	4.53	.34	4.53	.38	4.64	.36	4.47	.37	4.70	.37	4.50	.33	4.59	.37
M. Adductor Femoris	1.55	.12	1.70	.24	1.57	.19	1.61	.19	1.55	.21	1.56	.17	1.47	.18
M. Pectineus	.40	.08	.44	.06	.44	.03	.44	.06	.42	.04	.43	.04	.41	.03
M. Sartorius	.12	.09	.12	.02	.09	.02	.13	.03	.10	.03	.12	.03	.09	.01
M. Gemellus	.03	.01	.04	.02	.03	.01	.05	.03	.03	.01	.04	.01	.03	.01
M. Quadratus Femoris	.08	.06	.08	.02	.08	.02	.07	.03	.09	.03	.08	.02	.08	.02
M. Obturator Internus et Externus	.50	.12	.60	.10	.56	.06	.64	.10	.59	.06	.68	.11	.58	.07
M. Vastus Medialis	.74	.10	.73	.13	.82	.13	.72	.14	.89	.08	.70	.09	.88	.10
M. Vastus Intermedius	.66	.10	.64	.12	.63	.11	.63	.14	.59	.09	.63	.11	.59	.05
M. Articularis Genu	.04	.02	.06	.02	.06	.03	.08	.08	.05	.02	.06	.02	.04	.01
M. Iliacus	.58	.13	.55	.12	.63	.07	.57	.09	.64	.07	.56	.14	.63	.07

*23 kg group from study 1

Table 18. (cont'd)

Study			1		2		1		2		1		2	
Liveweight (kg)	23*		68		68		91		91		114		114	
Muscle	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE
No. of animals	17		30		24		30		24		32		24	
Muscle Group 2														
Distal Pelvic Limb														
M. Gastrocnemius et Soleus	1.85	.12	1.92	.15	2.09	.14	1.85	.13	2.06	.18	1.86	.17	1.90	.18
M. Flexor Digitorium Superficialis	.33	.03	.37	.05	.36	.04	.35	.06	.34	.04	.37	.07	.32	.05
Mm. Extensor Group	.49	.06	.47	.11	.46	.08	.42	.10	.49	.05	.45	.13	.47	.03
M. Peronaeus Longus	.15	.05	.09	.05	.14	.02	.09	.05	.14	.02	.09	.06	.13	.02
M. Extensor Digiti Quarti Proprius	.15	.03	.14	.06	.16	.02	.15	.04	.17	.02	.15	.04	.15	.01
M. Tibialis Anterior	.03	.03	.10	.06	.06	.06	.10	.05	.02	.01	.10	.05	.02	.01
M. Tibialis Posterior	.07	.02	.07	.03	.06	.01	.07	.03	.06	.01	.07	.02	.06	.01
M. Popliteus	.22	.02	.19	.04	.22	.03	.19	.03	.21	.02	.19	.02	.20	.02
M. Flexor Digitorum Longus	.13	.03	.14	.03	.13	.03	.13	.03	.13	.01	.13	.02	.11	.01
M. Flexor Hallucaias Longus	.54	.07	.50	.16	.51	.06	.47	.06	.48	.08	.47	.07	.46	.04

Table 18. (cont'd)

Study			1		2		1		2		1		2	
Liveweight (kg)	23*		68		68		91		91		114		114	
Muscle	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE
No. of animals	17		30		24		30		24		32		24	
Muscle Group 3														
Spinal														
M. Psoas Minor	.19	.06	.20	.04	.18	.04	.20	.04	.19	.04	.20	.04	.17	.03
M. Psoas Major	1.72	.31	1.79	.15	1.65	.15	1.74	.17	1.70	.14	1.74	.16	1.64	.12
M. Quadratus Lumborum	.17	.03	.18	.03	.16	.03	.20	.05	.21	.23	.20	.04	.17	.02
M. Iliocostalis	.70	.17	.58	.09	.56	.07	.64	.09	.53	.08	.59	.07	.55	.06
M. Longissimus Dorsi	10.69	.85	10.91	.65	10.93	.63	11.30	.98	10.80	.65	11.08	.72	10.82	.63
M. Spinalis Dorsi	1.46	.14	1.55	.27	1.32	.29	1.42	.34	1.44	.17	1.49	.26	1.54	.39
Mm. Multifidi Dorsi	1.75	.23	1.71	.24	1.93	.48	1.78	.34	2.07	.39	1.97	.40	2.09	.25
M. Longissimus Cervicis	.18	.19	.14	.05	.13	.04	.14	.05	.11	.02	.13	.05	.11	.03
Muscle Group 4														
Abdominal														
M. Cutaneous Trunci	4.26	.45	3.83	.81	2.74	.37	3.55	.65	2.84	.36	3.84	.71	2.85	.40
M. Serratus Dorsalis Caudalis	.24	.06	.18	.08	.23	.05	.19	.06	.24	.07	.18	.07	.24	.07
M. Obliquus Externus Abdominis	2.36	.25	2.33	.23	2.30	.14	2.33	.31	2.26	.23	2.39	.22	2.26	.18
M. Retractor Costae	.04	.02	.10	.05	.05	.02	.11	.09	.04	.02	.11	.04	.05	.02
M. Obliquus Internus Abdominis	1.09	.08	1.18	.14	1.05	.08	1.08	.08	1.08	.11	1.06	.08	1.03	.08
M. Transversus Abdominis	1.72	.19	1.34	.25	1.38	.23	1.37	.15	1.36	.16	1.35	.41	1.32	.12
M. Rectus Abdominis	1.85	.15	1.89	.31	1.74	.23	1.90	.26	1.71	.17	1.79	.27	1.72	.13
M. Diaphragm	.82	.31	.52	.19	.67	.24	.47	.12	.60	.07	.42	.09	.60	.08

Table 18. (cont'd)

Study			1		2		1		2		1		2	
Liveweight (kg)	23*		68		68		91		91		114		114	
Muscle	x	SE	x	SE	x	SE	x	SE	x	SE	x	SE	x	SE
No. of animals	17		30		24		30		24		32		24	
Muscle Group 5														
Proximal Thoracic Limb														
M. Deltoideus	.37	.04	.37	.04	.35	.04	.38	.04	.35	.03	.38	.03	.35	.04
M. Infraspinatus	1.60	.28	1.73	.15	1.78	.16	1.71	.15	1.83	.19	1.74	.11	1.82	.16
M. Triceps Brachii (Caput Laterale)	.74	.09	.65	.11	.76	.09	.68	.05	.73	.05	.71	.07	.75	.05
M. Teres Minor	.18	.05	.15	.05	.17	.03	.18	.04	.16	.03	.15	.05	.16	.03
M. Triceps Brachii (Caput Longum)	3.09	.22	2.99	.20	3.05	.19	2.98	.18	3.09	.20	2.95	.22	3.07	.18
M. Tensor Fasciae Antibrachii	.25	.07	.21	.05	.21	.05	.21	.05	.23	.03	.23	.05	.26	.04
M. Supraspinatus	2.20	.19	2.11	.20	2.18	.11	2.11	.15	2.28	.17	2.09	.27	2.34	.13
M. Biceps Brachii	.42	.04	.39	.04	.39	.04	.39	.06	.38	.02	.37	.04	.38	.03
M. Teres Major	.61	.05	.57	.05	.54	.04	.57	.06	.56	.04	.55	.10	.57	.05
M. Coracobrachialis	.10	.02	.10	.02	.09	.01	.12	.06	.09	.01	.14	.08	.09	.01
M. Subscapularis	.78	.08	.77	.11	.73	.06	.74	.06	.73	.06	.72	.07	.74	.06
M. Brachialis	.63	.04	.52	.06	.54	.05	.49	.07	.54	.02	.52	.06	.54	.04
M. Brachiocephalicus	1.04	.21	1.14	.38	.87	.15	1.09	.46	.90	.11	1.05	.41	.98	.11
M. Triceps Brachii	.46	.34	.33	.06	.34	.03	.32	.08	.32	.02	.30	.07	.31	.04

Table 18. (cont'd)

Study			1		2		1		2		1		2	
Liveweight (kg)	23*		68		68		91		91		114		114	
Muscle	X	SE	X	SE	X	SE	X	SE	X	SE	X	SE	X	SE
No. of animals	17		30		24		30		24		32		24	
Muscle Group 6														
Distal Thoracic Limb														
M. Extensor Carpi Radialis	.56	.05	.53	.05	.56	.04	.51	.06	.55	.04	.50	.04	.55	.04
M. Extensor Digitorum Longus	.07	.02	.07	.02	.08	.01	.07	.01	.07	.01	.06	.01	.07	.01
M. Extensor Digitorum Communis	.11	.04	.10	.02	.11	.03	.09	.03	.10	.01	.09	.02	.10	.01
M. Extensor Digitorum Lateralis	.09	.03	.08	.02	.09	.02	.08	.02	.08	.02	.08	.02	.08	.02
M. Extensor Carpi Ulnaris Lateralis	.06	.03	.06	.03	.04	.01	.07	.03	.04	.01	.06	.04	.04	.01
M. Extensor Carpi Obliquus	.04	.01	.03	.01	.04	.01	.03	.01	.03	.01	.05	.12	.04	.02
M. Flexor Carpi Radialis	.12	.06	.09	.02	.10	.01	.12	.08	.09	.01	.10	.03	.09	.01
M. Flexor Carpi Ulnaris	.07	.09	.10	.09	.05	.01	.06	.03	.05	.01	.11	.11	.05	.01
M. Flexor Digitorum Sublimis	.37	.06	.33	.06	.36	.04	.32	.09	.35	.03	.32	.05	.35	.04
M. Flexor Digitorum Profundus	.48	.11	.41	.10	.51	.03	.42	.11	.48	.04	.36	.08	.46	.05
M. Anconaeus	.16	.07	.12	.03	.12	.02	.11	.02	.12	.01	.12	.02	.11	.02

Table 18. (cont'd)

Study			1		2		1		2		1		2	
Liveweight (kg)	23*		68		68		91		91		114		114	
Muscle	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE
No. of animals	17		30		24		30		24		32		24	
Muscle Group 7														
Thorax to Thoracic Limb														
M. Latissimus Dorsi	2.22	.19	2.24	.19	2.10	.15	2.27	.17	2.18	.16	2.29	.39	2.23	.20
M. Trapezius Thoracis	.59	.07	.58	.07	.54	.05	.59	.06	.54	.08	.60	.07	.57	.07
M. Serratus Ventralis Thoracis	.90	.12	.90	.11	.88	.15	.97	.26	.86	.09	.88	.13	.88	.12
M. Pectoralis Profundus	2.81	.21	2.91	.26	2.73	.23	3.01	.35	2.72	.19	2.90	.24	2.79	.21
M. Pectoralis Superficialis	.80	.16	.82	.11	.73	.08	.84	.15	.76	.06	.80	.08	.76	.07
Muscle Group 8														
Neck to Thoracic Limb														
M. Trapezius Cervicalis	.54	.09	.52	.09	.45	.06	.56	.14	.45	.06	.63	.21	.50	.10
M. Omotransversarius	.18	.11	.39	.34	.10	.02	.34	.36	.10	.02	.44	.59	.10	.02
M. Rhomboideus	1.04	.14	1.01	.14	1.03	.18	1.00	.15	1.04	.12	.94	.13	1.06	.11
M. Serratus Ventralis Cervicis	2.75	.19	2.94	.29	3.04	.25	2.91	.29	3.12	.22	3.01	.32	3.16	.25

Table 18. (cont'd)

Study			1		2		1		2		1		2	
Liveweight (kg)	23 *		68		68		91		91		114		114	
Muscle	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE
No. of animals	17		30		24		30		24		32		24	
Muscle Group 9														
Neck and Thorax														
M. Intercostales	3.95	.57	3.93	.33	3.86	.37	4.04	.39	3.92	.27	4.11	.39	4.09	.24
M. Serratus Dorsalis Cranialis	.21	.07	.18	.05	.16	.03	.19	.04	.15	.02	.17	.03	.14	.02
M. Scalenus Dorsalis	.18	.08	.24	.06	.18	.05	.24	.11	.16	.05	.23	.08	.14	.03
M. Cervicohyoideus	.00	.00	.03	.03	.00	.00	.03	.04	.00	.00	.02	.04	.00	.00
M. Splenius	.85	.24	.94	.21	.95	.20	.92	.19	.92	.13	.91	.15	.92	.10
M. Scalenus Ventralis	.17	.04	.15	.02	.17	.02	.16	.05	.18	.03	.17	.06	.18	.04
M. Longus Capitis	.12	.07	.12	.04	.11	.04	.12	.02	.10	.03	.13	.03	.12	.02
M. Intertransversarius Longus	.18	.05	.15	.04	.20	.04	.18	.05	.20	.04	.19	.06	.21	.05
M. Longissimus Capitis and Atlantis	.26	.21	.16	.06	.17	.05	.22	.08	.18	.04	.21	.05	.19	.05
M. Intertransversarii Cervicis	.21	.07	.20	.06	.18	.06	.22	.06	.21	.05	.22	.07	.20	.06
M. Semispinalis Capitis	1.87	.37	2.09	.35	1.90	.43	2.32	.36	1.85	.32	2.00	.41	1.87	.30
M. Obliquus Capitis Caudalis	.41	.17	.58	.17	.43	.16	.66	.12	.47	.18	.68	.14	.53	.14
M. Rectus Thoracis	.09	.02	.08	.01	.07	.03	.09	.03	.07	.02	.08	.02	.06	.02
M. Transversus Thoracis	.28	.12	.20	.10	.23	.21	.20	.05	.17	.11	.21	.09	.14	.02
M. Longus Colli	.25	.06	.19	.05	.23	.06	.22	.04	.21	.05	.22	.08	.22	.04
Mm. Multifidi Cervicis	.23	.10	.21	.07	.15	.08	.19	.09	.17	.14	.23	.12	.14	.04

muscle from carcasses in study 1 which were prepared at a local packing plant. Those muscles affected by splitting the carcass and separation of the head were less damaged and more intact when preparation was done at the meats laboratory. These muscles weighed more than the more severely damaged and less complete muscles dissected after local abbatoir preparation and therefore resulted in a greater proportion of scrap. The only muscle knowingly affected by differences in dissection procedure was M. cutaneous trunci.

As liveweight increased from 23 to 114 kg, individual muscle percentages within each study either increased, decreased or remained relatively constant. Whether or not a muscle maintains a constant percentage over increasing liveweights or changes in percentage is a reflection of the growth impetus of that particular muscle. To express the relative growth impetus of the individual muscles more simply in these studies, growth coefficients (b values) and their standard errors (Sb) were calculated for each muscle and muscle group, and are presented in Table 19 and Figure 2. Calculations were made for each study by pooling data over all treatments and using the allometric regression formula, log Y= a + b log X with "Y" representing the individual muscle and "X" total muscle. Muscles with "b" values significantly greater than 1.0 ($P<0.05$, $P<0.01$) were

Table 19. Growth coefficients and standard errors for individual muscles and nine standard muscle groups with comparisons to other data.

Muscle Group	Study 1 b	s_b	Study 2 b	s_b	Sig. Diff.	Exp. 2** b	s_b	Davies (1974) Pietrain b	s_b	Large White b	s_b	Relative growth impetus pattern Pigs (1)	Pigs (2)	Cattle (3)	Sheep (4)
1. Proximal Pelvic Limb															
M. Tensor Fasciae Latae	1.12[a]	.023	1.13[a]	.028		0.93	.075	1.059[a]	.014	1.005	.023	HA	H or A	H	HA
M. Biceps Femoris	1.08[a]	.013	1.10[a]	.013		0.99	.031	1.067[a]	.015	1.057[a]	.014	HA	H	HA	HA
M. Glutaeus Medius	1.05[a]	.016	1.06[a]	.020		0.87[a]	.037	.997	.028	1.053	.028	HL	A	HA	HA
M. Glutaeus Accessorius	1.04	.031	1.03	.024		0.90	.049	1.045	.026	1.021	.027	A	A	A	A
M. Glutaeus Profundus	1.05	.053	1.05	.024		0.91	.060	1.048	.030	1.062	.062	A	A	L	AH
M. Rectus Femoris	1.02	.029	1.09[a]	.030		0.99	.036	1.021	.012	.987	.013	HA or A	A	L	AH
M. Semitendinosus	1.11[a]	.038	1.16[a]	.042		1.03	.047	1.078[a]	.017	1.036	.019	HA	H or A	HA	H
M. Gracilis	1.06[a]	.020	1.05[b]	.020		1.01	.050	1.026	.013	1.013	.013	HA	A	A	H
M. Semimembranosus	1.00	.016	1.01	.017		0.98	.046	1.073[a]	.029	1.043[a]	.015	A	H	HA	HA
M. Adductor Femoris	1.01	.025	.97	.026		0.90	.076	1.095	.096	1.043	.043	A	A	HA	H
M. Pectineus	1.08[a]	.035	1.04	.035		0.90[a]	.046	1.018	.019	1.003	.016	HL or AL	A	L	AH
M. Sartorius	1.10	.053	.95	.057		1.15	.124	.977	.059	.946	.047	A	A	L	L
M. Gemellus	1.25[a]	.095	1.01	.070	P<0.05	.68	.179					HA or A	--	L	L
M. Quadratus Femoris	1.08	.078	1.16[a]	.072		1.00	.130	.929	.043	1.026	.047	HA or A	A	L‡	L
M. Obturator Internus et Externus	1.23[b]	.037	1.13[b]	.031	P<0.05	1.09	.062	1.128	.061	1.046	.025	HA	A	L	A
M. Vastus Lateralis	1.03	.016	1.06[a]	.017		0.96	.042					HA or A	--	L	H
M. Vastus Medialis	.97	.034	1.11[b]	.029	P<0.01	1.08	.080	1.045[a]	.014	1.011	.014	HA or A	H or A	A‡	A
M. Vastus Intermedius	.96	.042	.92[a]	.030		0.89	.081					A or LA	--	L‡	LA
M. Articularis Genu	1.32[b]	.106	1.05	.095		0.25[b]	.236	.971	.040	.960	.057	HL or AL	A	L	--
M. Iliacus	1.00	.049	1.08[a]	.031		1.05	.064					A or HA	--	L	--
Muscle Group	1.08[b]	.021	1.06[b]	.015		0.93	.188					HA	--	HA or HL	H

a, b signify that b coefficient is significantly different from 1.0 at P<0.05 and P<0.01 significance levels respectively.
(1) indicates pig data from this study.
(2) indicates pig data from Davies (1974)
(3) data from Butterfield and Berg 1966a
(4) data from Lohse et al 1971
‡ doubtful classification
* growth coefficients with 23 group included
** growth coefficients with 23 group excluded
+ indicates muscle not classified

Table 19. (cont'd)

Muscle Group	Study 1 b	Study 1 S_b	Study 2 b	Study 2 S_b	Sig. Diff.	Exp. 2** b	Exp. 2** S_b	Davies (1974) Pietrain b	Davies (1974) Pietrain S_b	Davies (1974) Large White b	Davies (1974) Large White S_b	Relative growth impetus pattern Pigs (1)	Pigs (2)	Cattle (3)	Sheep (4)
2. Distal Pelvic Limb															
M. Gastrocnemius et Soleus	1.00	.016	1.03	.020		0.79[b]	.048	1.019	.018	1.020	.019	AL	A	L	L
M. Flexor Digitorium Superficialis	1.05	.034	.97	.029		0.71[b]	.075	.966	.035	.959	.020	AL	A	L	L
Mm. Extensor Group	.91	.055	.96	.028		1.03	.078					A	--	L	LA
M. Peronaeus Longus	.34[a]	.154	.92[b]	.035	P<0.01	.92	.079					LA	--	L	L
M. Extensor Digiti Quarti Proprius	.97	.074	1.07	.038	P<0.01	.92	.069					A	--	LA	L
M. Tibialis Anterior Cranialis	1.76[b]	.161	.48[b]	.158	P<0.01	.93	.413	.921[a]	.022	.925[a]	.018	HA or LA	L	L	L
M. Tibialis Posterior	1.04	.059	.98	.043		1.11	.111					A	--	L	H
M. Popliteus	.89[b]	.039	.93[b]	.020		.84[a]	.051	.962[a]	.018	.890[a]	.025	L	L	L	LA
M. Flexor Digitorum Longus	.98	.042	.93	.037		.85	.084					A	--	L	A
M. Flexor Hallucaias Longus	.90[a]	.045	.89[b]	.033		.79[a]	.090					L	--	L	AL
Muscle Group	.98	.108	.92	.051		.89	.154					A	--	HL or L	L

Table 19. (cont'd)

Muscle Group	Study 1 b	Study 1 s_b	Study 2 b	Study 2 s_b	Sig. Diff.	Exp. 2** b	Exp. 2** s_b	Davies (1974) Pietrain b	Davies (1974) Pietrain s_b	Davies (1974) Large White b	Davies (1974) Large White s_b	Relative growth impetus pattern Pigs (1)	Pigs (2)	Cattle (3)	Sheep (4)
3. Spinal															
M. Psoas Minor	1.07	.045	.96	.048		.96	.121					A	—	L	A
M. Psoas Major	1.03	.027	1.00	.029		.99	.047					A	—	HA	H
M. Quadratus Lumborum	1.10[a]	.041	.98	.059		1.16	.171					HA or A	—	L	A
M. Iliocostalis	.92[a]	.031	.82[b]	.031	P<0.05	.98	.078					LA	—	LA	LA
M. Longissimus Dorsi	1.05[b]	.015	1.01	.013	P<0.05	1.01	.033	1.120[a]	.016	1.075[a]	.013	HA or A	H	HA	HA
M. Spinalis Dorsi	1.00	.042	1.01	.041		1.25[a]	.117					AH	—	LA	A
M. Multifidi Dorsi	1.06	.037	1.14[b]	.045		1.25	.128					HA or A	—	L	A
M. Longissimus Cervicis	.93	.077	.83[a]	.073		.72	.161					LA or A	—	LA	A
Muscle Group	1.02	.023	.97	.037		1.04	.176					A	—	HA or A	HA
Muscle Group															
4. Abdominal															
M. Cutaneous Trunci	.90[a]	.039	.70[b]	.032	P<0.01	1.05	.078	1.104[a]	.040	1.119[a]	.046	LA	H	H	A
M. Serratus Dorsalis Caudalis	.78[a]	.095	.97	.060		1.01	.169					LA or A	—	A	A‡
M. Obliquus Externus Abdominis	1.00	.024	.96	.019		.95	.047	1.029	.026	.997	.033	A	A	HA	AH
M. Retractor Costae	1.61[b]	.133	1.05	.097		.80	.263					HA or A	—	A‡	—
M. Obliquus Internus Abdominis	.98	.020	.96	.018		.93	.050	1.043[a]	.017	1.224[a]	.062	A	H	H	H
M. Transversus Abdominis	.81[b]	.040	.81[b]	.030		.92	.084	1.069[a]	.027	1.013	.034	LA	H or A	HA	H
M. Rectus Abdominis	.97	.031	.94[b]	.021		.99	.058					LA or A	—	H	H
M. Diaphragm	.56[b]	.056	.82[b]	.058	P<0.01	1.00	.148					LA	—	—	—
Muscle Group	.95	.107	.90	.040		.96	.077					A	—	HA or H	H

Table 19. (cont'd)

Muscle Group	Study 1 b	Study 1 s_b	Study 2 b	Study 2 s_b	Sig. Diff.	Exp. 2** b	Exp. 2** s_b	Davies (1974) Pietrain b	Pietrain s_b	Large White b	Large White s_b	Relative growth impetus pattern: Pigs (1)	Pigs (2)	Cattle (3)	Sheep (4)
5. Proximal Thoracic Limb															
M. Deltoideus	.99	.019	.96	.023		1.18	.094	.934	.035	.927	.021	A	A	LA	L
M. Infraspinatus	1.06[a]	.025	1.11[b]	.029		1.02	.062	.968	.021	1.000	.017	HA	A	H‡	A
M. Triceps Brachii (Caput Laterale)	.96	.030	1.01	.019		1.03	.053	.850[a]	.018	.881[a]	.015	A	L	L	AL
M. Teres Minor	.89	.071	.94	.044		1.00	.047	.949	.040	.996	.045	A	A	L	LA
M. Triceps Brachii (Caput Longum)	.96[a]	.014	1.00	.013	P<0.05	.88	.105	.920[a]	.010	.945[a]	.012	LA or A	L	A	AL
M. Tensor Fasciae Antibrachii	.96	.050	1.02	.048		1.01	.036	.905	.061	.902	.027	A	A	A	A
M. Supraspinatus	.95	.024	1.04[a]	.015	P<0.05	1.11	.056	.885[a]	.024	.952[a]	.018	HA or A	L	L	AL
M. Biceps Brachii	.90[b]	.023	.93[b]	.017		1.13[a]	.036	.917	.020	.929	.013	LH	A	A	LA
M. Teres Major	.92	.040	.96	.018		.95	.043	.982	.027	.888	.012	A	A	A	AL
M. Coracobrachialis	1.14	.070	.96	.028	P<0.05	1.14	.043	.890[a]	.030	.933[a]	.026	A	L	L	A
M. Subscapularis	.94[a]	.023	.96	.018		1.15[a]	.060	.909[a]	.031	.958[a]	.015	LH	L	A	LA
M. Brachialis	.83[b]	.028	.89[b]	.015		1.03	.046	.885[a]	.016	.880[a]	.012	LA	L	L	L
M. Brachiocephalicus	.98	.076	.96	.039		1.00	.041	.947	.020	.930	.018	A	A	LA	—
M. Triceps Brachii	.75[b]	.065	.80[b]	.040		1.30[a]	.082	.869[a]	.034	.957	.029	LH	L or A	L‡	L
Muscle Group	.94	.025	.97	.019		1.05	.109					A	—	LA	AL

Table 19. (cont'd)

Muscle Group	Study 1 b	s_b	Study 2 b	s_b	Sig. Diff.	Exp. 2** b	s_b	Davies (1974) Pietrain b	s_b	Large White b	s_b	Relative growth impetus pattern Pigs (1)	(2)	Cattle (3)	Sheep (4)
6. Distal Thoracic Limb															
M. Extensor Carpi Radialis	.91[b]	.019	.98	.015	P<0.05	1.41[b]	.108	.862[a]	.013	.903[a]	.017	LH or AH	L	L	LA
M. Extensor Digitorum Longus	.91	.047	.96	.040		.97	.040	1.047	.085	.984	.012	A	A	LA	L
M. Extensor Digitorum Communis	.83[b]	.061	.93	.051		.67[b]	.076	.870[a]	.033	.882[a]	.029	L or AL	L	L	L
M. Extensor Digitorum Lateralis	.93	.066	.97	.053		.73	.103	.792[a]	.020	.833[a]	.062	A	L	LA	L
M. Extensor Carpi Ulnaris Lateralis	1.05	.100	.83[b]	.061		.98	.143	.802[a]	.031	.800	.047	A or LA	L	LA	L
M. Extensor Carpi Obliquus	.88	.082	.92	.058		1.01	.120	.825[a]	.020	.796[a]	.061	A	L	L	L
M. Flexor Carpi Radialis	.90	.075	.88[b]	.039		.86[a]	.056	.833[a]	.015	.922[a]	.028	AL or L	L	L	LA
M. Flexor Carpi Ulnaris	1.13	.140	.91	.063		.97	.063	.761[a]	.024	.898[a]	.038	A	L	LA	L
M. Flexor Digitorum Sublimis	.88	.066	.95	.025		.99	.114					A	—	L	L
M. Flexor Digitorum Profundus	.82[b]	.053	.99	.027	P<0.01	.91	.060	1.010	.025	1.060	.070	LA or A	A	L	L
M. Anconaeus	.79[b]	.052	.79[b]	.050		.82[b]	.054	.759[a]	.058	.849[a]	.042	L	L	--	L
Muscle Group	.91[b]	.030	.92[b]	.019		.94	.192					LA	--	LA or L	L
Muscle Group															
7. Thorax to Thoracic Limb															
M. Latissimus Dorsi	.98	.031	.99	.018		1.10[a]	.046	.927[a]	.018	.912[a]	.023	AH	L	H	AL
M. Trapezius Thoracis	1.00	.024	.96	.028		1.10	.076	.946	.027	.948	.048	A	A	A	L
M. Serratus Ventralis Thoracis	.99	.033	.98	.027		1.06	.046					A	--	H	HA
M. Pectoralis Profundus	1.03	.018	.99	.016		1.02	.074	.955[a]	.014	.974	.016	A	L or A	A	HL
M. Pectoralis Superficialis	1.02	.031	.97	.029		1.05	.045					A	--	A	L
Muscle Group	1.00	.009	.98[a]	.006		1.07[a]	.033					AH or LH	--	H	L

Table 19. (cont'd)

Muscle Group	Study 1 b	Study 1 s_b	Study 2 b	Study 2 s_b	Sig. Diff.	Exp. 2** b	Exp. 2** s_b	Davies (1974) Pietrain b	Davies (1974) Pietrain s_b	Davies (1974) Large White b	Davies (1974) Large White s_b	Relative growth impetus pattern Pigs (1)	Pigs (2)	Cattle (3)	Sheep (4)
B. Neck to Thoracic Limb															
M. Trapezius Cervicalis	1.05	.045	.92[a]	.036	P<0.01	1.87[b]	.230					AH or LH	—	A	L
M. Omotransversarius	1.14	.213	.72[b]	.076		.97	.145	.952	.090	.934	.042	A or LA	A	AH	L
M. Rhomboideus	.93[a]	.029	1.00	.027		.99	.128	.819[a]	.038	.861[a]	.042	A or LA	L	AH	HA
M. Serratus Ventralis Cervicis	1.05[a]	.020	1.10[b]	.016		1.02	.074	1.015	.022	.979	.013	HA	A	H	HA
Muscle Group	1.04	.043	.94	.081		1.21	.438					A	—	AH	AL

Table 19. (cont'd)

Muscle Group	Study 1 b	S_b	Study 2 b	S_b	Sig. Diff.	Exp. 2** b	S_b	Davies (1974) Pietrain b	S_b	Large White b	S_b	Relative growth impetus pattern Pigs (1)	Pigs (2)	Cattle (3)	Sheep (4)
9. Neck and Thorax															
M. Intercostales	1.02	.021	1.02	.021		1.02	.065					A	—	H‡	LA
M. Serratus Dorsalis Cranialis	.89[a]	.048	.75[b]	.042	P<0.05	.97	.088					LA	—	LA	A‡
M. Scalenus Dorsalis	1.25[b]	.084	.94	.082	P<0.01	.89	.086					HA or A	—	L‡	A‡
M. Cervicohyoideus	.49[b]	.197	.00	.000		.00	.000					L+	—	—	—
M. Splenius	1.07	.050	1.08	.050		.94	.082					A	—	H	LA
M. Scalenus Ventralis	.98	.053	1.05	.039		1.19[a]	.095					AH	—	A	A
M. Longus Capitis	1.13	.068	1.09	.085		1.39[a]	.175					AH	—	—	—
M. Intertransversarius Longus	1.05	.062	1.13[a]	.052		1.21	.132					A or HA	—	L	LA
M. Longissimus Capitis and Atlantis	.96	.077	.86	.070		1.42[a]	.163					AH	—	L	LA
M. Intertransversarii Cervicis	1.04	.063	.97	.077		1.23	.203					A	—	—	—
M. Semispinalis Capitis	1.08	.043	1.01	.038		1.04	.106					A	—	LA	—
M. Obliquus Capitis Caudalis	1.42[b]	.053	1.17[a]	.079	P<0.01	1.36	.216					HA	—	A	LA
M. Rectus Thoracis	.97	.064	.78[a]	.090		1.06	.255					A or LA	—	A	—
M. Transversus Thoracis	.78[b]	.068	.54[b]	.090	P<0.05	.53	.257					LA	—	A	L
M. Longus Colli	.88[a]	.055	.89[a]	.049		1.03	.134					LA	—	LA	A
Mm. Multifidi Cervicis	.93	.081	.67[b]	.103		.93	.281					A or LA	—	L	LA
Muscle Group	.93	.212	.87	.073		1.08	.212					A	—	A	LA

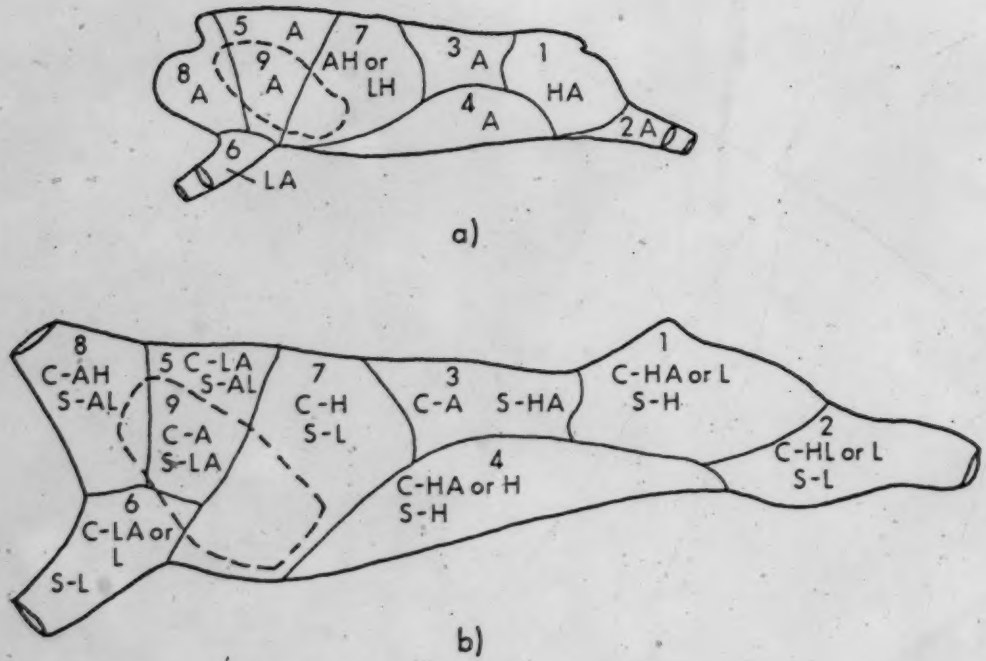

Figure 2. Relative growth impetus patterns of pigs (a) compared to cattle and sheep (b) where C- denotes cattle and S- denotes sheep.
H, A, and L - high, average and low growth impetus.
1 - 9 indicate muscle groups.

classified as being of high growth impetus (growing relatively faster than total muscle), those with b values significantly less than 1.0 ($P<0.05$, $P<0.01$) as low growth impetus (growing relatively slower than total muscle) and those with b values not different from 1.0 as average growth impetus (growing at the same relative rate as total muscle).

In Study 1, seventeen muscles had a high growth impetus and twenty-two a low growth impetus, while in Study 2, seventeen muscles were classified as high impetus, twenty-four as low impetus and one muscle was not classified. The remaining muscles in each study were classified as average growth impetus. Twenty-one muscles differed significantly ($P<0.05$, $P<0.01$) in classification between Studies 1 and 2. In most cases, differences in growth coefficients reflected the small but consistant differences in muscle percentage between Studies 1 and 2 noted earlier. Major differences were suspected for only three muscles. M. longissimus dorsi was classified as high impetus in Study 1 and average impetus in Study 2, M. triceps brachii (caput longum) and M. extensor carpi radialis were classified as low impetus in Study 1 but average impetus in Study 2 and M. supraspinatus was classed as average impetus in Study 1 but high impetus in Study 2.

As reported earlier (Table 11) there was evidence that some differentiation in muscle growth was still occurring at

23 kg liveweight. It was thought if this were the case, comparing regressions calculated over four liveweights (23 kg weight group included) with regressions calculated over three liveweights (23 kg weight group excluded) might assist in identifying those muscles with mono or diphasic growth patterns. Growth coefficients calculated over all liveweights for each of Studies 1 and 2 are compared with those calculated for Study 2 with the 23 kg liveweight group excluded (column (1) of Table 19). The results indicated that 33 muscles had diphasic growth impetus patterns for each of Studies 1 and 2 and that 22 muscles may have been either monophasic or diphasic in relative growth impetus. Forty one muscles had a monophasic growth pattern for each study. Davies (1974) compared growth coefficients of 62 muscles between Pietrain and Large White females which had been slaughtered through a 2 kg to 60 kg range in liveweight. The results were reported in terms of monophasic growth and did not inlcude diphasic growth patterns. However, comparing these results with the results of Studies 1 and 2 indicated relatively similar b values for most muscles. Different growth patterns did seem to be evident for five of the larger muscles (muscles weighing greater than 1% of total muscle). In three instances (M. semimembranosus, M. Cutaneous trunci, M. obliguus externus abdominis) results from Studies 1 and 2 indicated an average or low growth impetus while those of Davies (1974) indicated

a high growth impetus pattern. For M. supraspinatus and M. latissimus dorsi these classifications were reversed between Davies' study and Studies 1 and 2 here. Some of these differences may have been influenced by the starting weight between the studies. Davies used a starting weight of 2 kg while in this study a starting weight of 23 kg was used.

Growth patterns of individual muscles and muscle groups have been reported in cattle by Berg (1968) and Butterfield and Berg (1966a, b) and in sheep by Lohse et al., (1971). Comparisons of the relative growth impetus patterns of individual muscles and muscle groups from these two species and from pigs are given in Table 19. Classifications of individual muscles were generally similar among the three species although variations did occur for some muscles. In the pigs from Studies 1 and 2, three muscle groups were classified as diphasic (proximal pelvic limb, distal thoracic limb and thorax to thoracic limb). In cattle, only three muscle groups were classified as not being definitely diphasic (spinal, thorax to thoracic limb and neck and thorax). In sheep, the spinal, proximal thoracic limb, neck to thoracic limb and neck and thorax muscle groups were classified as diphasic. Of the muscle groups classed as monophasic, all were of average growth impetus in pigs, one was of high and one of low impetus in cattle and two were high and three low impetus in sheep. These observed

differences could reflect some differences in function but are probably more a reflection of sexual development and maturity. Relative to mature liveweights, both the cattle and sheep used in these studies were more physiologically mature than were the pigs. In addition, the cattle and sheep were studied from birth while the pigs in these studies were studied after weaning.

D) Discussion

Increases in liveweight between birth and maturity are accompanied by an early phase of differential muscle development followed by a phase of more constant muscle growth. In cattle, maximum muscle differentiation takes place prior to 240 days of age (Butterfield and Berg, 1966a, b) and in pigs at or before 23 kg liveweight. As liveweight increases beyond these critical points to maturity, muscle distribution remains relatively constant and is influenced only slightly by genetic or environmental factors (Berg and Mukhoty, 1970; Butterfield, 1963; Richmond and Berg, 1971b; Lohse, 1973). After maturation, sexual differences in muscle distribution may become more pronounced (Butterfield and Berg, 1972). The data from this study did not include pigs that had reached full maturity and therefore muscle distribution appeared relatively constant with only minor differences between sexes noted for some muscle groups.

The proximal pelvic limb, distal pelvic limb, abdominal

and expensive muscle group "A" (proximal and distal pelvic limb) were affected directly by either liveweight, breed or sex as well as interactions between breed, liveweight and feeding level. However, in each case the differences observed were very small and may have been due more to response to feeding levels or onset of maturity than breed or sex.

Differences in growth of the abdominal muscles in response to different levels of feed intake have been previously noted in cattle (Murray et al, 1974), in sheep (Lohse et al, 1971) and in pigs (Walker et al, 1968a, b). In each case those animals consuming the greater quantities of feed also contained a greater proportion of muscle in the abdominal region. Seebeck (1973) observed that weight loss in cattle affected the muscle weight distribution by causing the relative proportion of abdominal muscles to fall and Lodge and Heap (1967) observed an increase in weight of abdominal muscles during pregnancy in sows.

In Study 2, pigs fed at the 3.2% level were most restricted in intake and had a smaller percentage of abdominal muscle at each liveweight than those fed at the higher levels. In addition, the more restricted pigs were increasing in percentage abdominal muscle as liveweight increased, whereas the less restricted pigs had apparently reached their maximum relative growth for these muscles much

earlier as evidenced by the percentage decrease in abdominal muscle at the heavier liveweights.

Breed by liveweight interactions in percentage abdominal muscle might also be explained by feed intake. YL pigs had a slightly greater percentage of abdominal muscle at all liveweights than did YLY pigs. In a previous data analysis (Wilson, 1971) it was observed that the YL breed group also had the higher realized level of feeding throughout the study. They would therefore probably have developed a larger capacity to handle this intake.

Differentiation in muscle growth and the manifestation of changes in relative growth impetus of individual muscles may be explained as a response to functional demands placed on the muscles at various stages of development (Berg and Butterfield, 1975; Davies, 1974). Muscles responsible for mobility immediately after birth, such as the distal limb muscles, are well developed at birth and have a low growth impetus relative to the growth of total muscle from then on while those muscles responsible for propulsion, such as the proximal limb muscles, have a high growth impetus in the immediate post natal phase as the animal becomes more mobile. Muscles responsible for posture, such as those muscles around the spinal column, grow at a rate relative to the growth rate of total muscle throughout life and have an average growth impetus although again there may be an

immediate post natal spurt. Diphasic growth patterns are somewhat difficult to demonstrate using allometric equations since so much depends on the starting point and range of measurements. However, muscles do appear to exhibit waves of growth impetus in response to changes in functional demands. Examples of such growth patterns for pigs, cattle and sheep are presented in Table 19. In all three species, the relative growth impetus of the distal pelvic and thoracic limb muscle groups are classified as being of either low or average growth impetus indicating early or average development, while the proximal pelvic limb muscle group is classed as a high or high-average impetus group, indicating more prolonged development. The spinal column muscle group is of average growth impetus in pigs but average or high average in cattle and sheep. Again these differences may reflect differences in starting points.

Not all muscles within a muscle group have the same relative growth impetus pattern however. For example, while the spinal column muscle group has an average growth impetus, the major muscle in this group (M. longissimus dorsi) has a high average or high growth impetus in pigs and a high average impetus in cattle and sheep. Lohse et al. (1971) have noted that generally, within a muscle group, the deeper muscles have a lower growth impetus than the larger more superficial muscles.

In a previous study (Richmond and Berg, 1971b) growth patterns of muscle groups in pigs were tentatively classified relative to their percentage increase or decrease as liveweight increased. In that report the spinal and abdominal muscle groups were thought to be high-average and low-average impetus, respectively. Over the range of the present data these muscle groups appear to be more monophasic than diphasic with an average growth impetus. In contrast the distal thoracic limb muscle group was previously classifed as low impetus but was found here to be diphasic with a low-average growth pattern. Muscle group 7 (thorax to thoracic limb) was previously classified as average growth impetus but because of the response to sex-breed and sex- ration interactions, it was suggested at the time, that this muscle group may actually be diphasic. Results from these calculations confirm this suspicion and suggest that this muscle group should be classified as average high or low high impetus.

As a means of determining what, if any, differences might exist in the relative growth impetus patterns of individual muscles and muscle groups among pigs, cattle and sheep, comparisons were made with data collected and analysed in a comparable manner (Table 19) (Fig. 2). From these data, muscle growth in pigs appeared to be more monophasic than that in cattle and sheep. Six muscle groups

in cattle and four muscle groups in sheep were classed as diphasic but only three muscle groups in pigs were diphasic. This may have been due to major differential growth in pigs occurring prior to 23 kg liveweight or that the cattle and sheep used by Butterfield and Berg (1966a, b) and Lohse et al. (1971) were exhibiting greater differential growth as a result of sexual maturation. From the data available, sheep appear to exhibit a more prolonged differential development of the proximal pelvic and spinal muscle groups than is evident in pigs or cattle. Cattle and pigs on the other hand appear to have a more prolonged development of the thorax to thoracic limb muscle group than do sheep. The abdominal muscles of cattle and sheep appear to be later developing than those in pigs. But as was noted previously, this is probably a functional response to larger abdominal cavity contents. The remaining muscle groups (proximal and distal thoracic limb and the neck and thorax muscle group), were either of average, low, average-low or low-average growth impetus in all three species. Muscle group 8 (neck to thoracic limb) showed more prolonged differential growth in cattle than in pigs or sheep. This may have been due to the degree of maturity in the cattle or differential maturation response.

Growth impetus and relative muscle distribution may be specific in response to sexual maturity. Mature pigs may or

may not exhibit similar differential growth in neck and thorax muscles as has been observed in mature rams (Lohse, 1973) and bulls (Butterfield and Berg, 1972). Neither Davies' studies (1974) nor the studies presented here, included pigs which had reached full maturity.

The relative growth impetus of muscles and subsequent muscle distribution is dependent on muscle function. Considerable differences exist between species in the relative proportion of various muscles and muscle groups. Berg and Butterfield (1975) compared muscle distribution in cattle to that of the pigs from Study 1, sheep, water buffalo, banteng, moose, deer, bison and elephant seals. Compared to cattle, the pigs, sheep, deer and elephant seal all had a greater proportion of muscle around the spinal column indicating that these muscles may serve a mobility function as well as a support function in these species. On the other hand, pigs had relatively less muscle in the proximal and distal thoracic and pelvic limbs indicating a reduced agility compared to cattle but the banteng, moose and deer had a considerably greater proportion of muscle in these muscle groups indicating a much greater agility and functional usage of these muscles. It is somewhat sobering to realize that species which have evolved in a system of natural selection may have a comparatively greater proportion of muscle in the more desirable regions of the

carcass than those species which have undergone intensive artificial selection for these traits.

Major changes in muscle distribution within a species would require a major change in muscle function. It is unlikely that, within any species, functional requirements could be changed enough to result in major differences in muscle distribution among animals. This does not exclude the possibility of manipulating muscle distribution through genetic means, however. Davies (1974) has indicated genetic differences in very diverse breeds of pigs and Butterfield and Berg (1972) have suggested that changes in muscle-weight distribution may be effected by androgen levels. Byrne et al. (1973) compared the weights of seven muscles from mice which had been selected either for increased or decreased body weight. Selection for high body weight produced increases in the weight of all muscles sampled, and selection for low body weight produced decreases in the weight of all muscles sampled. However, this may not have been a differential response of the sampled muscles but merely a reflection of a general increase or decrease in muscle mass relative to body size. Gregory (1933) indicated that muscle growth may be regulated by general, group and specific genetic factors.

Further investigations of muscle growth and distribution within species should be directed towards

determining the various genetic and biochemical controls which regulate the development of this tissue. There may also be justification in evaluating production systems that might utilize those species which already have a more "desirable" muscle distribution in the carcass.

III. Growth of Chemical Components in Muscle

A) Introduction

Chemical Changes in Body Composition

A review of early reports concerned with chemical composition of the body by Garrett (1968) indicated that researchers observed early evidence of similarities in chemical composition within species. As fattening increased percentage body water decreased. Moulton (1923) suggested that on a fat-free basis the chemical composition of the body within a species was relatively constant but that the water content of the fat-free body decreased with age. The term "chemical maturity" was coined by Moulton to describe the period at which the chemical components of the fat-free body became relatively constant. Moulton considered this period to be at 4.0 to 4.5% of total life expectancy.

In more recent reports Moulton's description of chemical maturity has been criticized as being too general. Spray and Widowson (1950) compared the chemical composition of different species of animals and concluded that chemical maturity was not the same for all body constituents nor for different species. Sheng and Huggins (1971) noted that in the beagle dog, various chemical components of the body reached a plateau at very different ages and liveweights. The most dramatic changes in body fat and water occurred immediately after birth while Na and Cl were considered

"mature" at birth and Ca at approximately two months of age. Bailey et al. (1960) considered that attainment of mature fat-free size coincided with chemical maturity while Gordon et al. (1966) suggested that the influence of nutritional, genetic and environmental factors could play a role in determining chemical maturity.

Clawson et al (1955) indicated that, in pigs of approximately 225 pounds (102 kg) and 34 to 36% total body fat, percentage water, on a fat-free basis, stabilised at approximately 75.3 percent while Lawrie (1961a) indicated that in cattle percentage water becomes assymptotic at 24 months of age at 76.6 percent. Osinska and Ziotecka (1972) found that percent protein in the carcass of bulls remained relatively constant (18.9 to 19.9%) between 43 and 426 kg liveweight while Filer and Churella (1963) and Dickerson and Widdowson (1960) indicated that percent protein remained relatively constant in the pig after six weeks of age.

Some of the discrepency in establishing the period at which chemical composition becomes relatively stable may be in the difference of equating composition to age or weight. Mitchell and Hamilton (1929) compared the chemical composition of pigs of various weights and ages and proposed that body composition was related to body weight and not age. Reid et al. (1968) found that age and empty-body weight were correlated but that empty-body weight accounted for a

greater proportion of the variability in body constituents than did age. Tulloh (1963) examined data from a number of studies and concluded that body composition was more closely related to empty-body weight than age or nutritional history. Pitts and Bullard (1968) studied adults of a wide variety of mammalian species and found body composition to be directly related to body size.

2. Growth Patterns of Chemical Components in the Body

Gross chemical composition of the body in adult animals of different species is relatively constant (A.S.A.P., 1963; Maynard and Looslie, 1962). However, gross chemical composition is dependent on the fat content of the animal and the weight at which it is studied. Reid et al (1968) have shown wide variations in gross chemical composition of the body both within and between species when animals were studied from birth to maturity.

As an animal matures and liveweight increases the percentage of water and nitrogen in the body decreases and percentage fat increases (Brooks et al., 1964; Callow, 1947, 1948; Clawson, 1955; Elson et al., 1963; Garrett, 1968; Gnaedinger et al., 1963; McMeekan, 1940c; Mitchell and Hamilton, 1929; Palson and Verges, 1952a, b; Spray and Widdowson, 1950; Wardrop, 1963; Wood and Groves, 1963). Data from some of these reports are summarized in Tables 20 and 21 while Figure 3 depicts these changes in the pig. Robb et

Table 20. Chemical Composition of Pig Carcasses as Reported by Different Researchers

Researchers	Breed	Age	Weight	Sex	Percentage			
					Water	Nitrogen or Protein	Fat	Ash
Brooks et al. (1964)			50 lbs.	Mixed	61.0	15.3	22.1	0.73
			100 lbs.		53.0	15.5	30.4	0.78
			150 lbs.		50.0	14.2	34.8	0.67
			200 lbs.		46.0	13.2	39.9	0.67
Clawson, et al. (1955) (whole body analysis)	Chester White		226 lbs.		43.5	11.9	42.2	2.5
	Berkshire		214 lbs.		46.3	12.5	38.6	2.6
	Yorkshire		204 lbs.		46.6	12.6	38.2	2.6
Gnaedinger, et al. (1962, 1963) (fat free empty body and whole body analysis)			181-	Mixed	74.51	21.26		4.23
			220 lbs.		49.03	13.69	33.0	2.72
Wood and Grove (1965)		1 d.	1.0 kg	M	80.0	11.7	2.2	4.15
		5 d.	2.0 kg	FM	74.1	12.7	9.0	3.22
		8 d.	3.6 kg	M	71.1	14.4	10.3	2.70
		8 d.	3.2 kg	FM	72.0	14.2	10.2	3.02
		37 d.	13.6 kg	M	66.8	15.0	14.0	2.92
		37 d.	10.7 kg	FM	65.9	14.1	16.5	2.99
		65 d.	29.9 kg	M	63.9	14.8	17.3	3.18
		65 d.	22.2 kg	FM	65.3	14.0	16.1	3.13

Table 21. Chemical Composition of Carcasses from Other Species as Reported by Different Researchers.

Researcher	Species	Breed	Age	Weight	Sex	Percentages			
						Water	Protein	Fat	Ash
Searle (1970)	Sheep		3 d.	3.9-5.9 kg	Mixed	77.2	18.8		3.9
			18 mo.	26.9-46.0 kg	"	73.6	20.3		5.6
Robb et al. (1972)	Horse	Shetland	8 mo.-18 yr.		Mixed	70.66	22.60	6.6-18.9	5.98

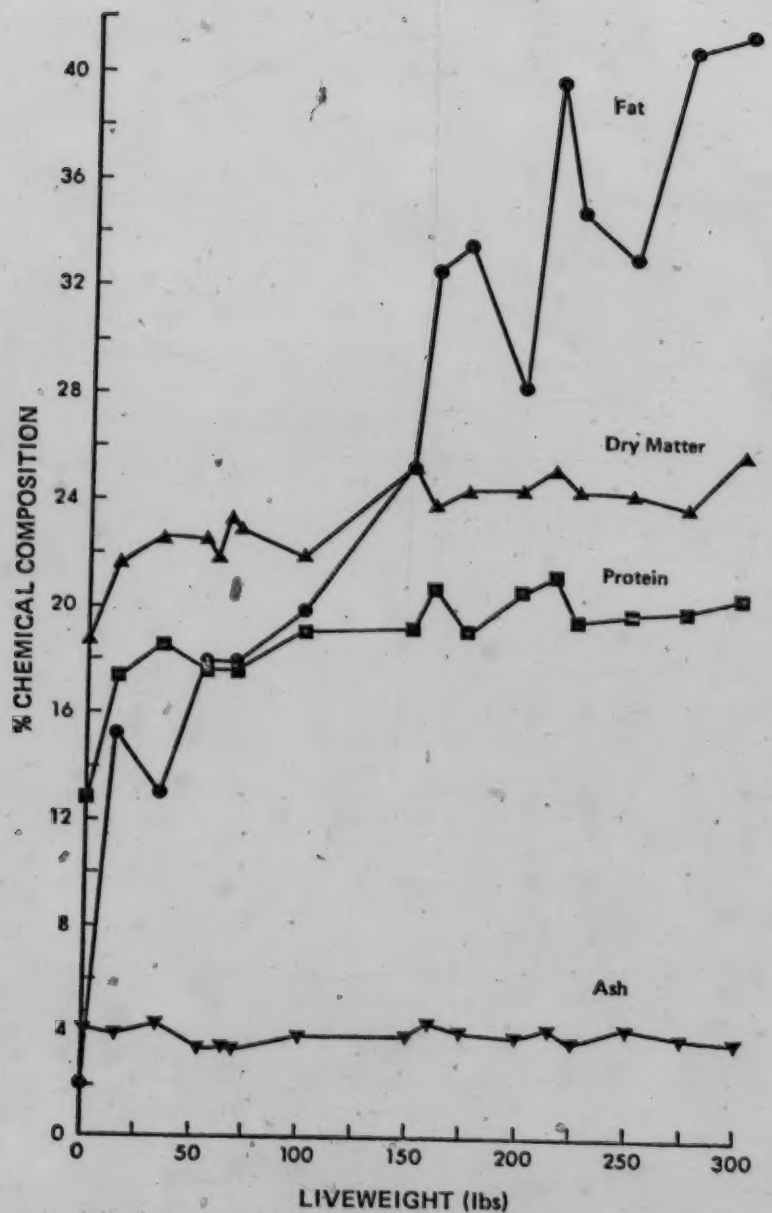

Figure 3. Chemical composition of pigs at different liveweights (plotted from data cited by Mitchell and Hamilton, 1929).

al. (1972) found that over 90% of the variation in the concentration of body fat in horses was associated with the variation in water concentration. In pigs, sheep and cattle, Reid et al. (1968) indicated that 94.8 to 97.4% of the variation in fat concentration was due to the variation in concentration of water and that the rate of change in fat concentration per unit change in water percentage was greater in sheep (-1.3068) than in pigs (-1.1095) or cattle (-1.1182).

On a fat-free basis as the concentration of water in the body decreases nitrogen and ash increase. Several reports have shown the inverse relationship between water and nitrogen (Clawson et al., 1955; Gnaedinger et al., 1963; Lawrie et al., 1963; Lawrie and Gatherum, 1964; Walker et al., 1968b). Reid et al. (1968) have shown that on fat-free basis the body of the pig contains more water and less protein and ash than that of sheep or cattle but on a fat-free dry basis the pig contains the most protein and least ash followed by sheep and cattle.

3. Growth Patterns of Chemical Components in Muscle

Deposition of the major chemical components of individual muscles follow the same general pattern as that found in the whole body. As liveweight increases percentage moisture, nitrogen and ash decrease and percentage fat increases. A number of studies reporting on the chemical

composition of various muscles in pigs and other species are summarized in Tables 22 and 23.

While a general pattern of chemical growth in muscles exists, there is little uniformity in chemical composition either within or between muscles. Lawrie (1961a) noted that in cattle percent fat and nitrogen were lower in the lumbar region of the longissimus dorsi muscles than in the thoracic region but that as young bulls became more mature the lumbar region contained the greatest percentage fat. In pigs percent water, fat and nitrogen were reported to be lower in the lumbar region than the thoracic region of the longissimus dorsi muscle (Lawrie et al., 1963). But, as in the case of beef cattle, increases in liveweight caused a shift in fat deposition to the lumbar region. Pigs at 150 pounds liveweight had a smaller percentage of fat in the lumbar region than the thoracic region of the longissimus dorsi muscle but at 200 pounds liveweight the lumbar region contained the greater percentage of fat.

Species differences also exist in the chemical composition of different muscles. Terrell et al. (1969) indicated that, in cattle, percent fat in the psoas major muscle exceeded that in the longissimus dorsi muscle but Allen et al. (1967) and Lawrie et al. (1963) indicated that, in pigs, percent fat in the longissimus dorsi muscle exceeded that of the psoas major muscle.

Table 22. Composition of Various Muscles or Carcass Joints in Pigs as Reported by Different Researchers

Researcher	Breed	Age	Weight	Sex	*Muscle or Joint	Percentages: Water	Nitrogen or Protein	Fat	Ash
Gillett et al. (1965)			220 lbs.	Barrows	LD	72.01	21.52	4.76	
					ST	73.13	19.68	6.03	
Heap and Lodge (1967)			155.0 kg.	Sows	LD	74.13	3.69	1.47	
Kolaczyk and Koteck (1965)			96.0 kg.	Gilts	LD	74.82	3.64	1.74	
				Barrows		74.44	3.61	2.25	
Lawrie et al. (1963) (LD avg. lumbar and thoracic)	Large-White		150 lbs.	Hogs	LD	77.10	3.66	2.95	
			200 lbs.			76.82	3.69	3.13	
			250 lbs.			76.02	3.83	3.83	
			150 lbs.		ECR	79.33	3.29	1.45	
			200 lbs.			79.20	3.35	1.32	
			250 lbs.			78.67	3.44	1.40	
Lawrie and Gatherum (1964)	Large-White		200 lbs.	Hog	LD	76.36	3.60	1.36	
				Gilt		75.62	3.74	1.35	
	Landrace		200 lbs.	Hog	LD	76.10	3.68	1.89	
				Gilt		76.29	3.59	1.63	
	Welsh		200 lbs.	Hog	LD	76.70	3.66	3.05	
				Gilt		75.90	3.61	1.87	
McMeekan (1940a) LD thorax region		Birth			LD	83.05		1.92	
		4 wks.				79.17		4.32	
		28 wks.				76.04		5.62	

*LD - M. longissimus dorsi
ST - M. semitendinosus
ECK - M. extensor carpi radialis

Table 22. (cont'd)

Researcher	Breed	Age	Weight	Sex	Muscle or Joint	Percentage			
						Water	Nitrogen or Protein	Fat	Ash
McMeekan (1940b) LD thorax region				Hogs	LD	74.94		2.26	
				Gilts		73.83		2.28	
McMeekan (1940c)				Hogs	LD	71.04		4.87	
				Gilts		72.53		4.15	
Topel et al (1966)			93-95 kg.	Barrows & Gilts	LD	72.30		4.21	
Walker et al. (1968)			56.7 kg.		Shoulder	78.07	3.44		
					Gammon	77.47	3.48		
					Back	76.17	3.69		
					Belly	76.96	3.57		

Table 23. Chemical Composition of Carcass Joints or Muscles in Other Species as Reported by Different Researchers.

Researchers	Species	Breed	Age	Weight	Sex	* Muscle or Joint	Percentage			
							Water	Nitrogen or Protein	Fat	Ash
Gillett et al. (1967)	Cattle			232-244 kg.	Steers	LD	70.83	21.50	6.21	
						ST	73.41	21.26	3.57	
Lawrie (1961b)	Cattle	Aryshire x Red Poll	16 wk.		Male	LD	77.60	3.54	1.97	
		Freisian	18 wk.		Male	LD	76.82	3.70	1.98	
		Angus	18 wk.		Female	LD	78.82	3.64	9.49	
		West Highland	32 wk.		Male	LD	79.17	3.60	11.94	
Lawrie et al. (1964)	Cattle		46 wk.		Female	LD	76.51	3.54	0.56	
						ECR	77.92	3.29	0.60	
Terrell et al (1969)	Cattle			386-455 kg.		LD			10.03	
						ST			5.97	
Ulyatt and Barton (1963)	Sheep		2 yrs.		Ewes	Leg	71.90	19.20	8.10	0.84
						Pelvis	70.30	19.30	9.60	0.84
						Loin	68.40	19.10	11.70	0.81
						9-10-11 rib cut	66.40	19.10	15.80	0.83
						Thorax	63.90	17.70	17.70	0.77
						Shoulder	69.60	18.70	11.00	0.82
						Neck	67.10	17.90	14.10	0.78
Vance et al. (1971)	Cattle			Carcass 161-333 kg.	Steers & Heifers	Whole side	47.87	15.41	33.93	2.79
						Chuck	53.27	16.78	26.94	2.82
						Rib	45.39	14.75	36.81	3.02
						Loin	48.92	15.69	32.79	2.58
						Round	53.99	17.58	25.33	3.10

*LD - M. longissimus dorsi
ST - M. semitendinosus
ECK - M. extensor carpi radialis

Table 23. (cont'd)

Researchers	Species	Breed	Age	Weight	Sex	Muscle or Joint	Percentage: Water	Percentage: Nitrogen or Protein	Percentage: Fat	Percentage: Ash
Zinn et al. (1966)	Cattle	Angus		Live wt. 230.4 kg.	Steers	Muscle of Carcass		18.92		
						Forequarter		17.86		
						Hindquarter		19.91		
						Round		20.06		
						Loin		19.76		
						Flank		19.54		

4. Factors Affecting Growth Patterns of Chemical Components

4.1 Breed Effects

Differences in chemical composition of the empty body relative to breed have been noted in sheep by Reid et al. (1968), McClelland and Russel, (1972), Searle and McGraham, (1972) but not by Arnold et al. (1969). In cattle Gillett et al. (1967) found that muscles from Hereford steers contained more fat and less moisture than those from Angus steers. In pigs Lawrie and Gatherum (1964) noted differences in percent chemical fat in the body of Large White (1.35%), Landrace (1.76%) and Welsh (2.41%). Gillett et al. (1965) reported that Yorkshire pigs had a greater percent of protein in the muscle group studied than did Hampshire pigs and McBee et al. (1969) reported that crossbreds (Duroc x Yorkshire x Tamworth) had a smaller percent fat in the longissimus dorsi muscle than did purebreds (Duroc) (5.9 vs. 11.9% respectively).

The influence of body type on chemical composition is not clear. Searle and McGraham (1972) suggested that within breeds of sheep small animals may contain more intramuscular fat than larger animals. However, Mitchell and Hamilton (1929) noted little difference in chemical composition of Poland China pigs of very diverse types. Reid et al. (1968) supported their observations after recalculating their data on a constant empty body weight basis.

4.2 Sex Effects

Several reports have noted differences between males and females in the chemical composition of carcasses, muscles or carcass joints. Bailey et al. (1966) noted that at 455 kg liveweight bulls had 7.6% fat in the longissimus dorsi muscle compared to 17.3% for steers. Terrell et al. (1969) noted that at 386 and 420 kg liveweight heifers had a slightly greater percent fat than steers at 455 kg but were similar in percent protein, water and ash. Suess et al. (1969) observed similar compositional differences between heifers at 386 kg liveweight and steers at 455 kg liveweight. In sheep Andrews and Orskov (1970) found that males contained more nitrogen and less fat than did females.

In pigs Lawrie and Gatherum (1964) noted sex differences relative to breed. Large White and Welsh hogs had a greater percentage of water than did gilts of these two breeds. Welsh hogs also exceeded gilts in percent fat. Large White gilts had a greater percentage of nitrogen than Large White hogs but in the Landrace breed, hogs had a greater percentage nitrogen than gilts. Kolaczyk and Kotik (1966) indicated that gilts had a greater percentage moisture, smaller percentage fat and similar percentage nitrogen compared to barrows when each were killed at 96 kg liveweight. McBee et al. (1969) reported that gilts and barrows had a similar percentage of fat in the longissimus

dorsi muscle at 125 pounds liveweight but at 200 pounds liveweight barrows exceeded gilts in percent fat in this muscle (8.8 vs. 7.0%). Wagner et al. (1963) indicated that gilts had slightly more nitrogen than barrows at 150 pounds liveweight but were similar to barrows at 200 pounds liveweight. Lawrie et al. (1964) noted that boars contained a greater percentage nitrogen and smaller percentage fat in the longissimus dorsi and extensor carpi radialis muscle than did barrows. Doornenbal (1967) indicated that barrows had a greater percent fat in the side than gilts but were similar to gilts in the ham, trimmed loin and shoulder.

Contrary to all these reports, Reid et al. (1968) reported that there was little evidence of sex differences in chemical composition from data they received. The only observation they noted was that from birth to 70 kg liveweight gilts had more body fat than barrows, were similar to barrows in body fat at 70 kg liveweight and less than barrows in body fat at liveweights above 70 kg. There is evidence, however, of sex hormone influences on chemical composition. Bailey et al. (1966) demonstrated that bulls implanted with 60 mg of stilbesterol increased in percent fat but that steers implanted with 24 mg of stilbesterol had a decrease in percent fat.

4.3 Nutritional Effects

Numerous studies on a variety of species have been

undertaken to evaluate the effect diet and feed intake might have on chemical composition of the body and many of these have come to different conclusions. The level of protein and energy in the diet have been credited with various effects. Norton et al. (1970) fed lambs diets containing either 12.0, 28.5 or 45.5% protein. When compared at the same body weight the fat content of body gain decreased and water and protein increased as dietary protein increased. Weight of fat in the empty body was similar between lambs at 8-9 kg empty body weight and lambs at 15 kg empty body weight when fed low and medium protein levels respectively. Lambs fed the 12.0% protein diet at 7 kg empty body weight were similar in fat weight to those fed the 45.5% protein diet at 13 kg empty body weight. Martin et al. (1963) noted that calves fed high energy rations contained a greater percent of fat and nitrogen and a smaller percent water than those fed normal energy levels. Andrews and Orskov (1970) found that sheep fed high levels of dietary protein had an increased nitrogen deposition and decreased fat concentration compared to those fed low levels of protein. However, Searle and McGraham (1972) and Reid et al. (1968) found no differences in chemical composition in sheep due to different dietary protein levels.

Wagner et al. (1963) compared various protein-energy rations in pigs and found a decrease in intramuscular fat

and increase in tissue nitrogen with increasing protein intake. Pigs on low energy diets differed less in fat content with increasing protein levels than did those pigs receiving high energy diets. Holme et al. (1964) and McBee et al. (1969) each reported decreases in fat and increases in nitrogen as dietary protein increased. However, McBee also noted that on a fat-free basis percent protein, water and ash were similar among dietary protein levels. Jenkinson et al. (1967) indicated that increased energy intake resulted in a decrease in percent water and an increase in percent fat with percent protein and ash remaining relatively constant. Filer and Churella (1963) found that pigs fed a 50% protein ration were similar in body weight and protein at two weeks of age as those fed a 14% protein ration at four weeks of age. At eight weeks of age body weights and composition were similar between the two protein levels. Reid et al. (1968) failed to detect any significant differences in body composition due to levels of dietary protein in pigs. Observations by Cohn (1963) indicate that specie differences may exist in response to protein intake. Percentage fat increased in rats as protein levels increased.

Level of feeding and restriction of feed appear to influence body composition differently in different species. Lee et al. (1971) compared the chemical composition of the

longissimus dorsi muscle among pigs which were either fasted, fasted and refed or fed a normal diet throughout. Fasted pigs had the most moisture and least fat while fasted refed pigs generally contained more fat than controls. McMeekan (1940b) reported that at sixteen weeks of age pigs on a high plane of nutrition had the greater percent fat and a smaller percent water in the psoas major and longissimus dorsi muscles. At 200 pounds liveweight pigs on a low-low plane of nutrition had the least fat and most water in these muscles while those on the low-high plane had the most fat and least water. Walker et al. (1968a, b) reported that pigs fed at high levels produced greater concentrations of fat but on a fat-free basis no differences in percent nitrogen or water were noted among feeding levels. Widdowson et al. (1960) found that undernourished pigs had more total water and less total nitrogen than well nourished pigs but when rehabilitated total water and nitrogen were similar to the well nourished pigs. Reid et al. (1968) found that sheep fed once a day gained less than those fed eight times per day but that at the same body weight chemical composition was not different. Only when sheep underwent periods of submaintenance energy intake was a difference noted in chemical composition. Fasted-refed sheep had less fat and slightly more protein and water than those on uninterrupted feeding. Cohn et al. (1963) compared rats which had been force fed twice per day with those fed ad libitum. Body gain

was similar but force fed rats contained a greater percent of fat and less of water and protein than did those fed ad libitum. The reports of Reid et al. (1968) in sheep and Cohn (1963) in rats may represent species differences in response to the rate at which food is ingested.

Objectives

In the studies reported here five muscles representing different relative growth patterns were selected to determine first what influence breed, sex, ration or feeding levels might have on the chemical composition of muscles taken from pigs of various liveweights and second what differences in chemical composition might exist among muscles of diverse functions.

B) Materials and Methods

The design and allotment of animals for each of the studies has been presented previously (pages 6 and 7). Five muscles (M. extensor carpi radialis (ECR), M. longissimus dorsi (LD), M. obliquus internus abdominis (OIA), M. rhomboideus (RH) and M. semitendinosus (ST)) were selected for chemical analysis from 100 of the 109 pigs dissected in Study 1 and all 72 pigs dissected in Study 2. The five muscles selected were chosen because they had been shown to represent different patterns of growth in cattle (Butterfield and Berg, 1966a). The relative growth patterns of the five muscles used for chemical analysis in these

studies were determined and were not found to be appreciably different from those in cattle (Table 19).

The five muscles were weighed at time of dissection and frozen. The frozen muscle was then sliced into sections, ground in an electric grinder and re-frozen. The frozen, ground muscle was then weighed and the moisture content determined after drying (AOAC 1965). The dried sample was homogenized by hand, a sample of the homoginate was used for ether-extract determination and the fat-free material from this sample was then used for nitrogen and ash determinations (AOAC 1965). All chemical determinations were done in duplicate and the analysis repeated if differences between duplicates exceeded five percent. Multiway analysis of variance and mean comparisons were carried out according to methods outlined by Steel and Torrie (1960).

C) Results

The chemical components of each of the five muscles as affected by liveweight, breed, sex, ration and feeding level in each of the studies are presented in Tables 24 to 27. The relative proportions of chemical components are expressed as percentages on a dry matter basis in Tables 24 and 25 and the relative rate of change of one chemical component to another are expressed as weight ratios in Tables 26 and 27. Two-way interactions among main effects found to be significant at the 5% level are presented in Tables 28 to

32. Data from the 23 kg liveweight group are presented as a reference point in Tables 24 to 27 but are not included in the statistical analysis. Weights of the chemical components for each muscle are presented in analysis of variance form in Appendix I for reference purposes.

In general, muscles sampled from pigs in Study 1 had slightly less water (W), nitrogen (N) and ash and slightly more intramuscular fat (F) on a percentage basis than muscles from pigs in Study 2. However, pigs in Study 1 were similar in percentage dissectible muscle, fat and bone to pigs in Study 2. Whether or not differences observed in chemical composition were a result of the main effects or sampling procedure can not be determined from these data.

1. Influence of Liveweight

Figures 4 and 5 depict the change in chemical composition of the composite of the five muscles on a weight and percentage basis for Studies 1 and 2. As liveweight increased from 23 to 114 kg ash increased the least rapidly followed by nitrogen, fat and water (Figure 4). Fat deposition paralleled that of nitrogen to 91 kg liveweight and then exceeded nitrogen in rate of deposition. On a percentage basis nitrogen and ash remained relatively constant, percentage water decreased and fat increased as liveweight increased (Figure 5).

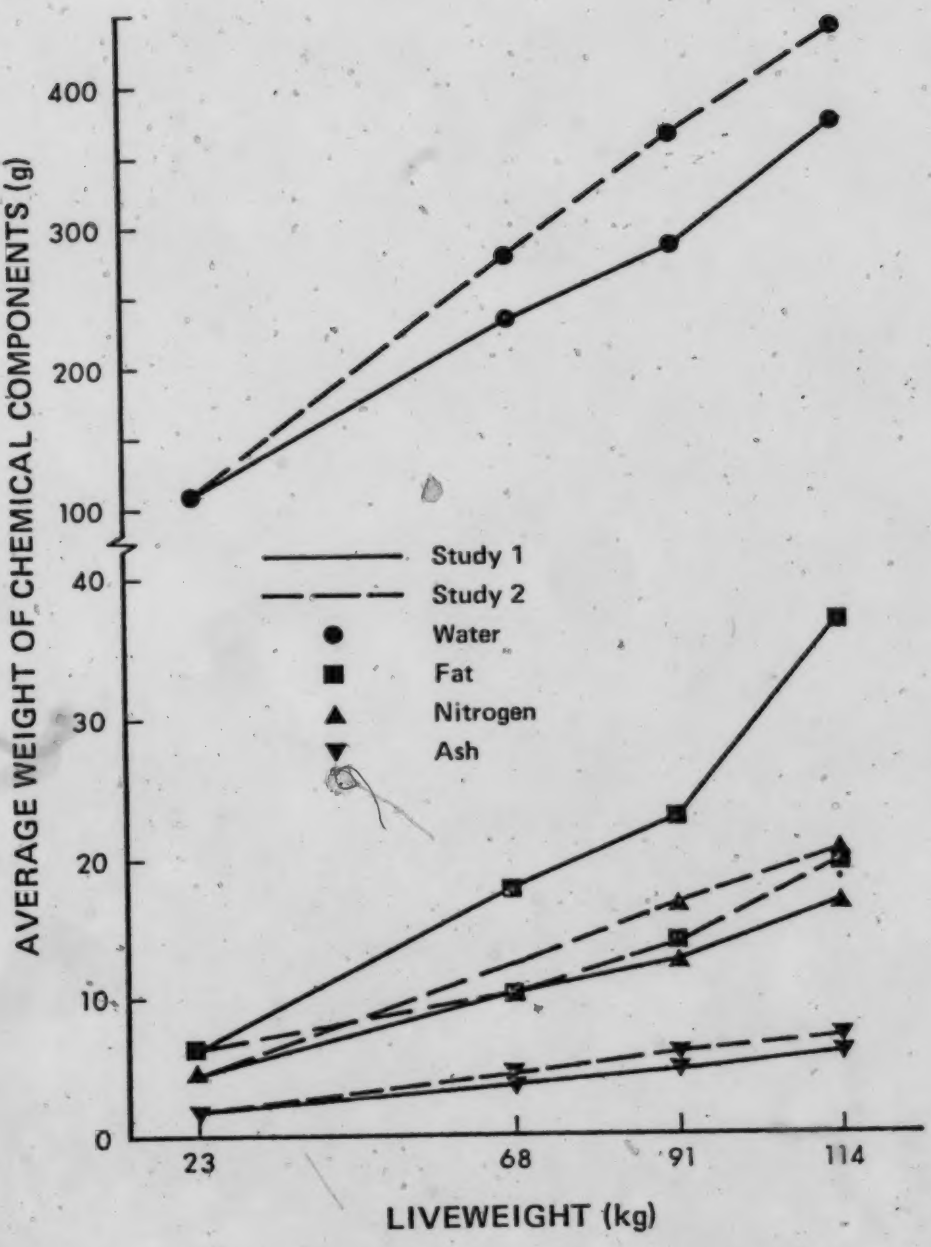

Figure 4. Average weight (g) of chemical components of five selected muscles relative to liveweight (kg).

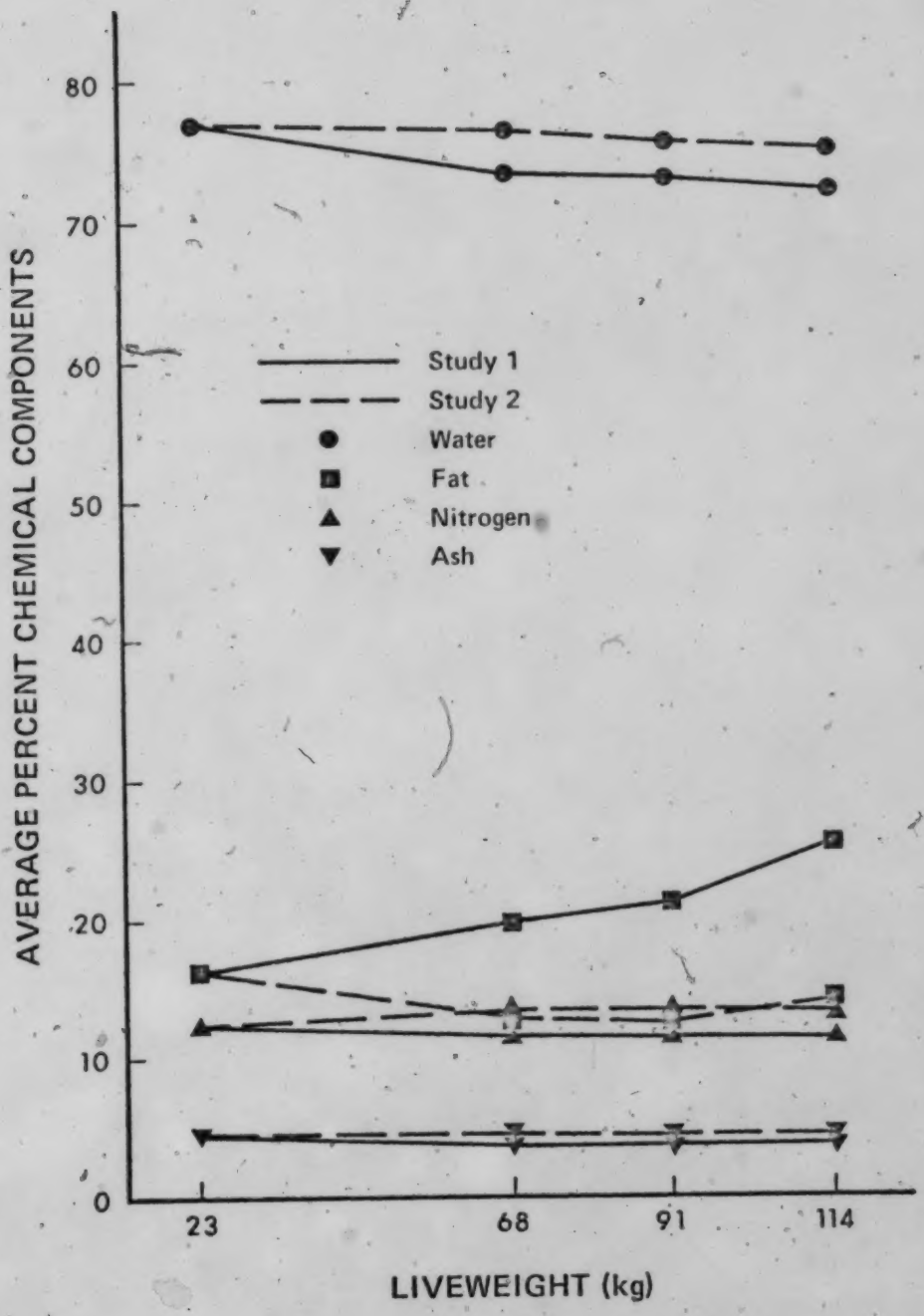

Figure 5. Average percent of chemical components of five muscles relative to liveweight.

Individual muscles varied in chemical composition. As is shown in Tables 24 and 25 in each study there was a significant decrease ($P<0.05$ and 0.01) in percent water with a corresponding significant increase in percent dry matter for the ECR, LD, RH and ST muscles as liveweight increased from 68 to 114 kg. Percent nitrogen decreased slightly in all five muscles in Study 1 as liveweight increased but none of the changes were significant. In Study 2 percent nitrogen decreased significantly ($P<0.05$ and 0.01) from 14.49 to 14.10% in the ECR, 14.12 to 13.71% in the LD and 13.20 to 12.57% in the ST muscle. Percentage fat increased from 11.60 to 17.99% in the ECR muscle, 19.53 to 26.84% in the LD muscle and 19.03 to 23.99% in the ST muscles from pigs in Study 1 and from 9.91 to 11.61% in the OIA muscles and 14.77 to 17.47% in the ST muscles from pigs in Study 2. No significant changes for percent ash were observed in either study as liveweight increased.

The relative weight changes of the chemical components of each muscle are expressed as ratios in Tables 26 and 27. As liveweight increased in each study, there were consistent increases in the nitrogen/water (N/W) and fat/water (F/W) ratios and consistent decreases in the nitrogen/fat (N/F) ratios for each of the muscles sampled. Significant increases ($P<0.01$) occurred in N/W ratios for the OIA and ST muscles in Study 1 and the ECR, LD, RH and ST muscles in

Table 24. Chemical composition of five muscles on dry matter basis (Study 1).

	Liveweight (kg)					Breed				Sex			Ration		
	23*	68	91	114	SE	DY	HY	YY	SE	Barrows	Gilt	SE	HE	LE	SE
No. of animals	17	27	27	29		23	33	27		42	41		42	41	
% Moisture															
M. Extensor Carpi Radialis	78.32	76.72^{A}	75.78^{B}	75.72^{B}	.216	76.32	75.69	76.21	.216	75.83	76.31	.176	75.85	76.30	.176
M. Longissimus Dorsi	76.08	72.94^{A}	72.64^{A}	70.93^{B}	.342	72.06	72.08	72.37	.342	71.24^{A}	73.10^{B}	.279	71.80	72.54	.279
M. Obliquus Internus Abdominis	78.26	74.27	73.16	73.51	.426	73.87	73.72	73.35	.426	73.30	74.00	.348	73.35	73.94	.348
M. Rhomboideus	74.61	70.12^{A}	70.26^{A}	67.86^{B}	.518	69.46	68.76	70.02	.518	68.43^{A}	70.40^{B}	.423	68.95	69.88	.423
M. Semitendinosus	78.04	74.05^{a}	73.52^{a}	72.47^{b}	.357	73.01	73.28	73.75	.357	73.00	73.69	.292	73.27	73.43	.292
% Dry Matter															
M. Extensor Carpi Radialis	21.68	23.37^{A}	24.22^{B}	24.28^{B}	.216	23.72	24.35	23.79	.216	24.21	23.71	.176	24.20	23.72	.176
M. Longissimus Dorsi	23.92	27.05^{A}	27.36^{A}	29.07^{B}	.342	27.94	27.90	27.63	.342	28.74^{A}	26.90^{B}	.279	28.18	27.46	.279
M. Obliquus Internus Abdominis	21.74	25.70	26.88	26.64	.426	26.13	26.49	26.60	.426	26.67	26.15	.348	26.77	26.04	.348
M. Rhomboideus	25.39	29.87^{a}	29.74^{a}	31.72^{b}	.518	30.54	30.81	29.98	.518	31.57^{A}	29.32^{B}	.423	30.77	30.11	.423
M. Semitendinosus	21.96	26.06^{a}	26.48^{a}	27.53^{b}	.357	27.00	26.82	26.25	.357	27.01	26.37	.292	26.79	26.59	.292
% Nitrogen Dry															
M. Extensor Carpi Radialis	13.32	13.19	13.09	13.27	.188	13.23	13.03	13.30	.188	13.07	13.30	.154	13.02	13.35	.154
M. Longissimus Dorsi	12.25	11.68	11.74	11.54	.149	11.80	11.52	11.65	.149	11.22^{A}	12.09^{B}	.121	11.43^{a}	11.88^{b}	.121
M. Obliquus Internus Abdominis	13.17	12.09	12.05	12.05	.196	12.18	11.90	12.12	.196	11.83	12.30	.160	11.90	12.23	.160
M. Rhomboideus	10.57	9.55	9.63	9.23	.158	9.39	9.38	9.64	.158	9.02^{A}	9.92^{B}	.129	9.39	9.55	.129
M. Semitendinosus	13.04	11.72	11.39	11.52	.683	11.64	11.34	11.66	.683	11.40	11.69	.558	11.45	11.66	.558
% Fat															
M. Extensor Carpi Radialis	10.47	11.60^{A}	11.70^{A}	17.99^{B}	.921	12.99	15.63	12.67	.921	15.74^{A}	11.79^{B}	.752	13.13	14.40	.752
M. Longissimus Dorsi	18.44	19.53^{A}	20.05^{A}	26.84^{B}	1.002	22.72^{ab}	23.71^{a}	19.99^{b}	1.002	25.41^{A}	18.86^{B}	.818	23.07	21.20	.818
M. Obliquus Internus Abdominis	11.55	15.68	18.75	19.03	1.199	16.29	18.79	18.37	1.199	18.91	16.73	.979	17.88	17.75	.979
M. Rhomboideus	27.69	33.98	34.23	38.74	1.582	35.62	37.34	33.99	1.582	38.67^{a}	32.64^{b}	1.292	36.08	35.23	1.292
M. Semitendinosus	12.81	19.03^{a}	21.31^{ab}	23.99^{b}	1.203	21.83	21.78	20.73	1.203	23.22^{a}	19.67^{b}	.983	22.22	20.67	.983
% Ash															
M. Extensor Carpi Radialis	4.34	3.93	4.06	4.08	.258	4.29	3.93	3.85	.258	3.93	4.12	.211	3.87	4.18	.211
M. Longissimus Dorsi	5.02	4.05	4.11	3.87	.413	4.16	4.15	3.72	.413	3.70	4.32	.338	3.95	4.07	.338
M. Obliquus Internus Abdominis	4.39	4.02	3.65	4.00	.303	4.03	4.00	3.64	.303	3.88	3.89	.247	3.84	3.93	.247
M. Rhomboideus	3.65	3.24	3.65	2.98	.271	3.22	3.32	3.35	.271	3.06	3.53	.221	3.37	3.22	.221
M. Semitendinosus	5.07	3.96	4.02	3.87	.378	4.30	4.04	3.51	.378	3.82	4.08	.309	3.90	4.00	.309

a, b, c and A, B, C = means within the same classification followed by different letters differ significantly at $P<0.05$ and $P<0.01$ respectively.

*23 kg group not included in statistical analysis

Table 25. Chemical composition of five muscles on dry matter basis (Study 2)

	Weight kg					Breed			Sex			Ration Level			
	23†	68	91	114	SE	YL	YLY	SE	Barrow	Gilt	SE	3.2%	3.7%	4.2%	SE
No. of animals	17	24	24	24		36	36		36	36		24	24	24	
% Moisture															
M. Extensor Carpi Radialis	78.32	78.34^{A}	77.47^{B}	76.54^{C}	.202	77.38	77.51	.165	77.48	77.41	.165	77.41	77.42	77.52	.202
M. Longissimus Dorsi	76.08	75.57^{A}	74.40^{B}	73.99^{B}	.209	74.56	74.74	.171	74.23^{A}	75.08^{B}	.171	74.65	74.52	74.79	.209
M. Obliquus Internus Abdominis	78.26	77.01	76.74	76.21	.259	76.37	76.94	.211	76.32^{a}	76.98^{b}	.211	76.68	76.50	76.77	.259
M. Rhomboideus	74.61	75.59^{A}	75.16^{AB}	74.37^{B}	.300	74.71	75.38	.245	74.80^{a}	75.29^{b}	.245	74.53	75.40	75.19	.300
M. Semitendinosus	78.04	76.84^{A}	75.56^{B}	74.61^{B}	.258	74.98^{A}	76.37^{B}	.211	75.51	75.83	.211	75.68	75.54	75.79	.258
% Dry Matter															
M. Extensor Carpi Radialis	21.68	21.66^{A}	22.53^{B}	23.46^{C}	.202	22.62	22.49	.165	22.52	22.59	.165	22.59	22.58	22.46	.202
M. Longissimus Dorsi	23.92	24.43^{A}	25.60^{B}	26.01^{B}	.209	25.44	25.26	.171	25.77^{A}	24.92^{B}	.171	25.36	25.48	25.21	.209
M. Obliquus Internus Abdominis	21.74	22.99	23.26	23.79	.259	23.63	23.06	.211	23.68^{a}	23.02^{b}	.211	23.31	23.49	23.23	.259
M. Rhomboideus	25.39	24.41^{A}	24.83^{AB}	25.63^{B}	.300	25.29	24.62	.245	25.20^{a}	24.71^{b}	.245	25.47	24.60	24.81	.300
M. Semitendinosus	21.96	23.16^{A}	24.42^{B}	25.39^{B}	.258	25.01^{A}	23.63^{B}	.211	24.47	24.17	.211	24.32	24.43	24.21	.258
% Nitrogen															
M. Extensor Carpi Radialis	13.32	14.49^{a}	14.15^{b}	14.10^{b}	.095	14.00^{A}	14.49^{B}	.078	14.19	14.30	.078	14.28	14.14	14.32	.095
M. Longissimus Dorsi	12.25	14.12^{A}	13.97^{AB}	13.17^{B}	.090	13.76^{A}	14.11^{B}	.077	13.81^{a}	14.06^{b}	.077	14.05	13.76	14.00	.090
M. Obliquus Internus Abdominis	13.17	13.93	14.05	13.56	.115	13.64^{A}	14.05^{B}	.093	13.71	13.98	.093	13.90	13.77	13.87	.115
M. Rhomboideus	10.57	11.87	12.45	12.00	.203	11.90	12.31	.166	11.82^{a}	12.39^{b}	.166	12.05	12.08	12.19	.203
M. Semitendinosus	13.04	13.20^{a}	13.10^{a}	12.57^{b}	.153	12.52^{A}	13.39^{B}	.126	12.78	13.13	.126	12.91	12.93	13.03	.153
% Fat															
M. Extensor Carpi Radialis	10.47	8.42	9.17	8.99	.461	9.74^{A}	7.98^{B}	.376	8.81	8.91	.376	8.21	9.52	8.85	.461
M. Longissimus Dorsi	18.44	9.68	9.51	11.01	.528	10.83^{a}	9.30^{b}	.431	10.99^{A}	9.14^{B}	.431	8.78^{b}	10.66	10.75^{a}	.528
M. Obliquus Internus Abdominis	11.55	9.91^{a}	9.08^{a}	11.61^{b}	.457	10.92^{a}	9.48^{b}	.373	10.89^{a}	9.51^{b}	.373	9.56	10.22	10.81	.457
M. Rhomboideus	27.69	22.23	19.50	21.34	1.154	22.22	19.82	.942	22.22	19.83	.942	21.48	20.01	21.58	1.154
M. Semitendinosus	12.81	14.77^{a}	15.46^{ab}	17.47^{b}	.760	18.96^{A}	12.84^{B}	.621	17.43^{A}	14.37^{B}	.621	15.51	16.49	15.70	.760
% Ash															
M. Extensor Carpi Radialis	4.34	4.49	4.60	4.58	.063	4.65^{a}	4.46^{b}	.052	4.59	4.52	.052	4.63	4.57	4.47	.063
M. Longissimus Dorsi	5.02	4.69	4.54	4.32	.151	4.44	4.59	.123	4.62	4.42	.123	4.56	4.46	4.52	.151
M. Obliquus Internus Abdominis	4.39	4.38	4.47	4.35	.069	4.40	4.40	.052	4.35	4.45	.052	4.53	4.36	4.31	.069
M. Rhomboideus	3.65	4.01	4.41	4.03	.135	4.17	4.12	.114	4.18	4.11	.114	4.33	4.12	3.99	.135
M. Semitendinosus	5.87	4.84	4.64	4.45	.157	4.60	4.69	.128	4.62	4.67	.128	4.84	4.58	4.51	.157

a, b, c and A, B, C – means within the same classification followed by different letters differ significantly at P<0.05 and P<0.01 respectively.

*23 kg group not included in statistical analysis

Table 26. Ratios of chemical components in five muscles as influenced by liveweight, breed, sex and ration (Study 1)

	Liveweight					Breed				Sex			Ration		
	23*	68	91	114	SE	DY	HY	YY	SE	Barrow	Gilt	SE	HR	LR	SE
No. of animals	17	27	27	29		23	33	27		42	41		42	41	
Nitrogen/water ratio															
M. Extensor Carpi Radialis	.040	.040	.042	.042	0.001	.041	.042	.041	0.001	.042	.041	0.001	.041	.042	0.001
M. Longissimus Dorsi	.040	.043	.044	.046	0.001	.045	.044	.044	0.001	.044	.044	0.001	.044	.045	0.001
M. Obliquus Internus Abdominis	.040	.042^{A}	.045^{B}	.044^{AB}	0.001	.044	.043	.044	0.001	.043	.044	0.001	.044	.043	0.001
M. Rhomboideus	.030	.041	.041	.042	0.001	.041	.042	.041	0.001	.041	.041	0.001	.042	.041	0.001
M. Semitendinosus	.040	.041^{A}	.041^{A}	.044^{B}	0.001	.043	.041	.041	0.001	.042	.042	0.001	.042	.042	0.001
Nitrogen/fat ratio															
M. Extensor Carpi Radialis	1.33	1.22^{A}	1.22^{A}	.82^{B}	0.067	1.13	.98	1.14	0.067	.94^{A}	1.23^{B}	0.055	1.09	1.08	0.005
M. Longissimus Dorsi	.79	.65	.63	.53	0.043	.61	.55	.65	0.043	.50^{A}	.71^{B}	0.035	.56	.64	0.035
M. Obliquus Internus Abdominis	1.21	.80	.70	.66	0.040	.77	.65	.74	0.040	.65^{A}	.79^{B}	0.033	.72	.72	0.033
M. Rhomboideus	.42	.29	.29	.26	0.018	.28	.27	.30	0.018	.25^{A}	.32^{B}	0.009	.27	.29	0.009
M. Semitendinosus	1.05	.66^{A}	.58^{AB}	.49^{B}	0.038	.53	.56	.61	0.038	.53^{a}	.64^{b}	0.031	.54	.62	0.031
Fat/water ratio															
M. Extensor Carpi Radialis	.030	.036^{A}	.038^{A}	.054^{B}	0.003	.041	.047	.040	0.003	.048^{A}	.037^{B}	0.002	.042	.043	0.002
M. Longissimus Dorsi	.060	.075^{a}	.078^{a}	.102^{b}	0.006	.088	.089	.078	0.006	.099^{a}	.071^{b}	0.005	.090	.080	0.005
M. Obliquus Internus Abdominis	.030	.056	.075	.075	0.009	.063	.076	.068	0.009	.073^{a}	.065^{b}	0.007	.070	.068	0.007
M. Rhomboideus	.100	.153^{ab}	.148^{a}	.188^{b}	0.012	.169	.169	.152	0.012	.183^{a}	.143^{b}	0.010	.170	.156	0.010
M. Semitendinosus	.040	.070^{A}	.079^{A}	.097^{B}	0.007	.083	.087	.075	0.007	.089	.075	0.006	.084	.080	0.006
Nitrogen/ash Ratio															
M. Extensor Carpi Radialis	2.82	3.56	4.08	3.58	0.539	3.13	3.77	4.32	0.539	3.94	3.54	0.440	3.97	3.50	0.440
M. Longissimus Dorsi	2.42	3.05	3.83	3.07	0.589	3.05	3.00	3.90	0.589	3.39	3.25	0.481	3.45	3.19	0.481
M. Obliquus Internus Abdominis	2.82	3.10	4.32	3.15	0.659	3.27	3.22	4.08	0.659	3.46	3.58	0.538	3.74	3.31	0.538
M. Rhomboideus	2.64	2.99	3.82	3.28	0.237	3.14	3.11	3.04	0.237	3.11	3.08	0.193	3.16	3.04	0.193
M. Semitendinosus	3.48	3.14	3.60	3.04	0.533	3.73	3.04	4.02	0.533	3.38	3.14	0.436	3.32	3.21	0.436
Fat/ash Ratio															
M. Extensor Carpi Radialis	2.38	3.18	3.55	4.61	0.463	3.20	4.35	3.88	0.463	4.35	3.21	0.378	3.96	3.59	0.378
M. Longissimus Dorsi	3.63	5.10	6.36	6.92	0.888	5.89	6.05	6.43	0.888	7.24^{a}	5.03^{b}	0.725	6.56	5.69	0.725
M. Obliquus Internus Abdominis	2.48	4.03	6.43	5.47	0.717	4.33	5.52	6.08	0.717	5.68	4.94	0.586	5.68	5.02	0.586
M. Rhomboideus	7.37	11.19	10.92	14.86	1.138	12.88	12.68	11.42	1.138	14.12^{a}	10.53^{b}	1.128	13.13	11.52	1.128
M. Semitendinosus	2.43	5.04	6.88	6.78	1.068	5.48	6.32	6.91	1.068	6.98	5.49	0.872	6.43	6.05	0.872
Water/ash Ratio															
M. Extensor Carpi Radialis	78.13	88.31	99.41	83.46	14.399	76.32	89.00	105.85	14.399	95.40	85.38	11.757	96.91	83.88	11.757
M. Longissimus Dorsi	62.97	69.89	87.58	66.91	13.557	67.63	68.51	88.23	13.557	76.63	72.95	11.069	78.56	71.02	11.069
M. Obliquus Internus Abdominis	77.41	74.46	97.80	71.81	15.499	74.97	74.81	94.29	15.499	80.70	82.01	12.655	86.03	76.68	12.655
M. Rhomboideus	76.92	73.65	74.47	76.42	5.167	76.16	73.69	74.70	5.167	75.59	74.11	4.218	75.39	74.11	4.218
M. Semitendinosus	67.75	76.78	91.79	69.12	15.317	63.10	73.20	101.40	15.317	82.71	75.75	12.506	81.33	77.13	12.506
Dry matter/ash Ratio															
M. Extensor Carpi Radialis	21.61	27.67	31.39	26.88	4.267	23.68	28.89	32.78	4.267	30.35	26.55	3.484	30.59	26.31	3.484
M. Longissimus Dorsi	19.78	26.07	32.48	26.72	4.834	26.01	25.91	33.35	4.834	30.03	26.82	3.947	30.04	26.31	3.947
M. Obliquus Internus Abdominis	21.47	25.70	35.66	36.23	5.072	26.83	27.03	33.72	5.072	29.41	28.98	4.141	31.34	27.05	4.141
M. Rhomboideus	26.22	31.64	31.42	36.63	2.746	34.11	33.30	32.27	2.746	35.27	31.19	2.242	34.36	32.10	2.242
M. Semitendinosus	19.04	26.62	32.16	26.48	4.759	23.65	26.97	34.63	4.759	29.85	26.99	3.886	29.03	27.81	3.886

a, b, c, and A, B, C - means within the same classification followed by different letters differ significantly at P<0.05 and P<0.01 respectively.

*23 kg group not included in statistical analysis

Table 27. Ratios of chemical components in five muscles (Study 2)

	Liveweight (kg)				Breed			Sex			Feeding Level			
	68	91	114	SE	YL	YLY	SE	Barrow	Gilt	SE	3.2%	3.7%	4.2%	SE
No. of animals	24	24	24		36	36		36	36		24	24	24	
Nitrogen/water ratio														
M. Extensor Carpi Radialis	.040^{A}	.041^{A}	.043^{B}	0.0004	.041	.042	0.0003	.041	.041	0.0003	.041	.041	.041	0.0004
M. Longissimus Dorsi	.045^{A}	.048^{B}	.048^{B}	0.0006	.047	.048	0.0005	.048	.047	0.0005	.048	.047	.047	0.0006
M. Obliquus Internus Abdominis	.046	.042	.042	0.0030	.045	.042	0.0020	.046	.041	0.0020	.047	.042	.042	0.0030
M. Rhomboideus	.038^{A}	.041^{B}	.041^{BC}	0.0004	.040	.040	0.0004	.040	.040	0.0004	.041	.040	.040	0.0004
M. Semitendinosus	.040^{A}	.042^{B}	.043	0.0005	.042	.042	0.0004	.041	.042	0.0004	.041	.042	.042	0.0005
Nitrogen/fat ratio														
M. Extensor Carpi Radialis	1.87	1.79	1.75	0.106	1.56^{A}	2.04^{B}	0.086	1.76^{A}	1.84^{B}	0.086	1.98^{B}	1.61^{A}	1.81^{A}	0.106
M. Longissimus Dorsi	1.66^{AB}	1.51^{A}	1.41^{B}	0.086	1.36^{a}	1.69^{b}	0.070	1.38^{a}	1.67^{b}	0.070	1.81	1.33	1.44	0.086
M. Obliquus Internus Abdominis	1.50^{A}	1.60^{B}	1.60^{AB}	0.076	1.33	1.59	0.062	1.36^{a}	1.56^{b}	0.062	1.54	1.41	1.43	0.076
M. Rhomboideus	.59^{A}	.66^{B}	.79^{B}	0.023	.58	.65	0.019	.56	.67	0.019	.62	.63	.60	0.023
M. Semitendinosus	1.00^{A}	1.00^{A}	.79^{B}	0.060	.74^{A}	1.12^{B}	0.049	.87	.99	0.049	.96	.89	.94	0.060
Fat/water ratio														
M. Extensor Carpi Radialis	.023^{a}	.026^{a}	.029^{b}	0.002	.029^{A}	.023^{B}	0.001	.026^{A}	.025^{B}	0.002	.023^{B}	.028^{A}	.026^{A}	0.001
M. Longissimus Dorsi	.032^{ab}	.034^{a}	.040^{b}	0.002	.038^{A}	.032^{B}	0.002	.040^{A}	.030^{B}	0.002	.030^{B}	.038^{A}	.037^{A}	0.002
M. Obliquus Internus Abdominis	.033	.027	.038	0.003	.038	.028	0.002	.038^{A}	.028^{B}	0.002	.033	.032	.034	0.003
M. Rhomboideus	.074	.066	.077	0.005	.080	.065	0.004	.078^{a}	.067^{b}	0.004	.075	.067	.076	0.005
M. Semitendinosus	.045	.051	.063	0.003	.063^{A}	.043^{B}	0.003	.058^{a}	.048^{b}	0.003	.052	.054	.052	0.003
Nitrogen/ash ratio														
M. Extensor Carpi Radialis	3.03	2.93	2.94	0.037	2.87^{A}	3.07^{B}	0.030	2.90^{A}	3.04^{B}	0.037	2.94	2.94	3.02	0.030
M. Longissimus Dorsi	2.95	2.92	3.04	0.082	2.94	3.00	0.067	2.86^{a}	3.08^{b}	0.067	2.96	2.96	3.00	0.082
M. Obliquus Internus Abdominis	3.43	3.00	3.01	0.242	3.25	3.05	0.198	3.28	3.01	0.198	3.35	3.04	3.05	0.242
M. Rhomboideus	2.85	2.78	2.93	0.074	2.79^{a}	2.92^{b}	0.061	2.78	2.93	0.061	2.74	2.87	2.95	0.074
M. Semitendinosus	2.67	2.73	2.73	0.067	2.63^{a}	2.79^{b}	0.054	2.68	2.74	0.054	2.58	2.76	2.78	0.067
Fat/ash ratio														
M. Extensor Carpi Radialis	1.75	1.87	1.88	0.101	2.00^{A}	1.67^{B}	0.083	1.82	1.85	0.083	1.69	1.98	1.87	0.101
M. Longissimus Dorsi	2.02	2.03	2.47	0.121	2.34^{a}	2.01^{b}	0.099	2.36^{a}	1.99^{b}	0.099	1.80	2.37	1.35	0.121
M. Obliquus Internus Abdominis	2.49	1.96	2.65	0.234	2.66^{a}	2.07^{b}	0.191	2.69^{a}	2.04^{b}	0.191	2.37	2.30	2.44	0.234
M. Rhomboideus	5.51^{a}	4.46^{a}	5.46^{b}	0.388	5.59^{A}	4.70^{B}	0.316	5.39^{a}	4.89^{b}	0.316	5.08	4.82	5.52	0.388
M. Semitendinosus	2.99^{a}	3.22^{a}	3.90^{b}	0.213	3.92^{A}	2.82^{B}	0.174	3.65^{a}	3.09^{b}	0.174	3.16	3.54	3.42	0.213
Water/ash ratio														
M. Extensor Carpi Radialis	75.87^{A}	71.97^{AB}	68.33^{B}	1.211	70.48^{a}	73.63^{b}	0.988	70.37^{a}	73.74^{b}	0.988	71.24	71.99	72.95	1.211
M. Longissimus Dorsi	64.97	61.05	63.38	1.947	63.24	63.03	1.589	60.13	66.14	1.589	62.44	63.17	63.78	1.947
M. Obliquus Internus Abdominis	73.31	70.58	70.98	1.000	70.55	72.69	0.817	71.19	72.06	0.817	69.96	72.32	72.60	1.000
M. Rhomboideus	74.73	67.90	70.55	1.850	69.54	72.58	1.510	69.60	72.52	1.510	67.65	72.06	73.47	1.850
M. Semitendinosus	67.49	64.44	64.26	1.848	63.56	67.24	1.509	64.86	65.93	1.509	63.03	66.08	67.03	1.848
Dry matter/ash ratio														
M. Extensor Carpi Radialis	20.95	20.76	20.82	0.210	20.51^{A}	21.18^{B}	0.171	20.44^{A}	21.24^{B}	0.171	20.63	20.86	21.04	0.210
M. Longissimus Dorsi	20.95	20.84	22.20	0.542	21.34	21.32	0.443	20.75	21.90	0.443	21.05	21.48	21.50	0.542
M. Obliquus Internus Abdominis	21.85	21.32	22.18	0.331	21.89	21.68	0.270	22.04	21.53	0.270	21.19	22.15	22.01	0.331
M. Rhomboideus	24.14	22.34	24.52	0.659	23.73	23.60	0.538	23.57	23.77	0.538	22.97	23.59	24.44	0.659
M. Semitendinosus	20.24	20.83	21.73	0.500	21.00	20.87	0.409	21.02	20.85	0.409	20.00	21.39	21.42	0.500

a, b, c, and A, B, C - means within the same classification followed by different letters differ significantly at $P<0.05$ and $P<0.01$ respectively.

Study 2. In each of these muscles nitrogen was increasing at a more rapid rate than water. In some muscles the rate of fat deposition exceeded that of water or nitrogen as liveweight increased. Significant increases ($P<0.05$ and 0.01) in F/W ratios were observed in the ECR, LD and ST muscles in Study 1 and the LD muscles in Study 2. N/F ratios decreased significantly ($P<0.01$) in the ECR and ST muscles in Study 1 and the OIA, RH and ST muscles in Study 2. Ratios which included ash did not change significantly as liveweight increased.

2. Influence of Breed

In Study 1 muscles from HY pigs appeared to have slightly less moisture and nitrogen and slightly more fat both on a percentage and weight-ratio basis. In only one instance were differences significant however. Percent fat in the LD muscle of HY pigs was significantly greater ($P<0.05$) than that in YY pigs. DY pigs were intermediate in % fat in the LD muscle to HY and YY pigs and not significantly different from either (Table 24).

In Study 2, breed groups appeared to have a greater effect on chemical composition of muscles (Tables 25 and 27). YL pigs had a significantly lower ($P<0.01$) percentage of moisture and nitrogen and a significantly higher ($P<0.01$) percentage of dry matter and ether-extract in the ST muscle than YLY pigs. The YL breed group also had a lower

percentage of nitrogen and a higher percentage of fat in the ECR, LD and OIA muscles than did the YLY breed group ($P<0.05$ and 0.01). Percentage ash in the ECR was significantly higher ($P<0.05$) in the YL pigs compared to the YLY pigs. This was the only instance where percentage ash differed due to treatment. The weight-ratios in Table 27 coincide with the percentage differences in Table 25. YL pigs had significantly lower ($P<0.05$ and 0.01) N/F ratios in the ECR, LD, OIA and ST muscles and significantly higher ($P<0.01$) F/W ratios in the ECR, LD, OIA and ST muscles than YLY pigs. Fat was being deposited at a more rapid rate than nitrogen in these muscles in the YL breed group as compared to the YLY breed group. Significant differences ($P<0.05$ and 0.01) were noted between the two breed groups in N/A, F/A and W/A ratios in the ECR, OIA and ST muscles but these were more a result of the changes already noted in nitrogen, fat and water than to changes in weight of ash.

3. Influence of Sex

In Study 1, barrows had a lower percentage of water and nitrogen and a higher percentage of dry matter in the LD and RH muscles and a higher percentage of fat in the ECR, LD, RH and ST muscles than did gilts ($P<0.05$ and 0.01) (Table 24). As shown by the N/F and F/W ratios in Table 26 fat was being deposited at a more rapid rate than either nitrogen or water in the muscles of barrows compared to those of gilts ($P<0.05$

and 0.01).

In Study 2, barrows had a lower percentage of water and a higher percentage of dry matter in the LD, OIA and RH muscles, a lower percentage of nitrogen in the LD and RH muscles, a higher percentage of fat in the LD, OIA and ST muscles and a similar percentage of ash in all muscles compared to gilts ($P<0.05$ and 0.01) (Table 26). As in Study 1, the N/F ratios for the LD, OIA and RH muscles and the F/W ratios for the LD, OIA and ST muscles indicate that barrows were depositing fat more rapidly than nitrogen or water compared to gilts. Some of the ratios which included ash were significantly different between sexes but as with the influence of breed these were more a result of changes in nitrogen, fat and water than changes in ash.

4. Influence of Ration and Feeding Level

Ration and feeding level did not appear to have any appreciable effect on the chemical composition of the muscles sampled. In Study 1, the only significant difference ($P<0.05$) was for percent nitrogen in the LD muscle. Pigs fed the HE ration had a slightly lower percentage of nitrogen in this muscle than those fed the LE ration (Table 24). No significant differences occurred in weight ratios.

In Study 2, pigs fed at the 3.2% level had a significantly lower ($P<0.05$) percentage of fat in the LD

muscle as compared to those fed at either the 3.7 or 4.2% levels. This difference was reflected in a significantly ($P<0.01$) higher N/F ratio and smaller F/W ratio in the LD muscle (Table 27).

5. Interactions Among Liveweight, Breed, Sex, Ration and Feeding Level

Significant interactions ($P<0.05$ and $P<0.01$) between liveweight and breed group affected the percent nitrogen and N/F ratio in the RH muscle from pigs in Study 1 and percent ash in the ECR and LD muscles from pigs in Study 2 (Table 28a, b, c, d).

In Study 1, HY pigs had the higher percentage nitrogen and N/F ratios in the RH muscle at 68 and 114 kg liveweight and the lower percentage nitrogen and N/F ratios at 91 kg liveweight. YY pigs had the higher percent nitrogen and N/F ratios at 91 kg liveweight. Although HY pigs had a higher percentage of nitrogen at 114 kg liveweight, DY pigs had the higher N/F ratio indicating that, at this liveweight, the rate of nitrogen deposition was greater than that of fat for this breed group compared to the other two breed groups.

In Study 2, weight interactions affected the percentage ash in the ECR and LD muscles. For each muscle YL pigs had a slightly lower percentage of ash at 68 kg liveweight and higher percentage at 91 and 114 kg liveweight than YLY pigs.

Table 28.

a) Weight by breed interaction on % nitrogen in the RH muscle (Study 1)

Weight (kg)	68	91	114
Breed DY	9.20	9.70	9.30
HY	9.82	8.87	9.44
YY	9.64	10.32	8.97

b) Weight by breed interaction on N/F ratio in the RH muscle (Study 1)

Weight (kg)	68	91	114
Breed DY	0.26	0.30	0.29
HY	0.31	0.23	0.26
YY	0.30	0.35	0.24

c) Weight by breed interaction on % ash in the ECR muscle (Study 2)

Weight (kg)	68	91	114
Breed YL	4.47	4.61	4.87
YLY	4.50	4.59	4.29

d) Weight by breed interaction on % ash in the LD muscle (Study 2)

Weight (kg)	68	91	114
Breed YL	4.26	4.62	4.45
YLY	5.11	4.46	4.19

Table 29.

a) Weight by sex interaction on % fat in the LD muscle (Study 1)

Weight (kg)		68	91	114
Sex	Barrow	21.19	22.48	32.56
	Gilt	17.86	17.61	21.11

b) Weight by sex interaction on % nitrogen in the LD muscle (Study 2)

Weight (kg)		68	91	114
Sex	Barrow	14.06	14.02	13.34
	Gilt	14.18	13.93	14.08

c) Weight by sex interaction on F/W ratio in the LD muscle (Study 2)

Weight (kg)		68	91	114
Sex	Barrow	0.350	0.358	0.489
	Gilt	0.283	0.324	0.309

d) Weight by sex interaction on % nitrogen in the OIA muscle (Study 2)

Weight (kg)		68	91	114
Sex	Barrow	13.70	14.18	13.25
	Gilt	14.16	13.92	13.87

e) Weight by sex interaction on N/F ratio in the ST muscle (Study 2)

Weight (kg)		68	91	114
Sex	Barrow	0.86	1.08	0.65
	Gilt	1.14	0.91	0.93

Generally, percentage ash in each muscle appeared to increase in the YL breed group and decrease in the YLY breed group as liveweight increased from 68 to 114 kg.

Weight x sex interactions were noted in Study 1 for percentage fat in the LD muscle and in Study 2 for percentage nitrogen and F/W ratio in the LD, percentage nitrogen in the OIA and N/F ratio in the ST muscle (Table 29a, b, c, d, e).

In Study 1, percentage fat in the LD muscle was higher in barrows than in gilts at each liveweight. As liveweight increased, percentage fat increased in barrows but in gilts no noticeable increase occurred until 91 kg liveweight. In Study 2, percentage nitrogen in the LD muscle of barrows decreased slightly while that in gilts remained relatively constant as liveweight increased. At 114 kg liveweight, gilts had a slightly higher percent nitrogen in this muscle group than did barrows.

The F/W ratio in the LD muscle of barrows increased as liveweight increased and was greater than that of gilts at each liveweight. Gilts increased in F/W ratio between 68 and 91 kg liveweight and then decreased slightly at 114 kg liveweight.

Gilts exceeded barrows in percentage nitrogen in the OIA muscle at 68 and 114 kg liveweight but at 91 kg these

positions were reversed. This same pattern was reflected in the N/F ratio of the ST muscle. At 68 and 114 kg liveweight gilts appeared to be depositing more nitrogen and less fat than barrows but at 91 kg liveweight, barrows deposited more nitrogen relative to fat than did gilts.

Weight x ration and weight x feed level interaction effects are shown in Table 30 (a to j) ($P<0.05$). At 68 kg liveweight percentage fat in the ECR muscle from pigs in Study 1 was highest for those fed the HE ration but at 91 and 114 kg liveweight, percentage fat was highest for those fed the LE ration (Table 30a).

In Study 2, a somewhat similar pattern was observed in percent fat, moisture, N/F ratio, F/W ratio and N/W ratio for the ECR muscle (Table 30, b, d, e, f, g) ($P<0.05$). At 68 kg liveweight pigs fed at the 3.2% level had a lower percentage of fat and water, a higher N/F ratio, a lower F/W ratio and a higher N/W ratio in the ECR muscle than those fed at the 3.7 or 4.2% levels of feed. At 91 kg liveweight, pigs fed at the 4.2% level had the lower percentage fat, higher percentage water and N/F ratio and lower F/W ratio than those fed at the 3.2 or 3.7% levels. N/W ratio was similar for all feed levels at this liveweight. At 114 kg liveweight, positions were again reversed between pigs fed at the 3.2% level and 4.2% level: the ECR muscle of pigs fed at the 3.2% level contained greater concentrations of

Table 30.

a) Weight by ration interaction on % fat in the ECR muscle (Study 1)

Weight (kg)		68	91	114
Energy	HE	12.89	10.98	15.53
	LE	10.32	12.42	20.45

b) Weight by feed level interaction on % fat in the ECR muscle (Study 2)

Weight (kg)	68	91	114
Feed Level			
3.2%	7.28	9.79	7.56
3.7%	8.23	10.56	9.79
4.2%	9.76	7.16	9.63

c) Weight by feed level interaction on % fat in the OIA muscle (Study 2)

Weight (kg)	68	91	114
Feed Level			
3.2%	8.85	9.45	10.39
3.7%	9.39	8.97	12.31
4.2%	11.48	8.81	12.14

d) Weight by ration interaction on % water in the ECR muscle (Study 2)

Weight (kg)	68	91	114
Feed Level			
3.2%	77.95	77.23	77.04
3.7%	78.95	77.10	76.21
4.2%	78.12	78.08	76.35

Table 30. (Cont'd)

e) Weight by feed level interaction on N/F ratio in the ECR muscle (Study 2)

Weight (kg)	68	91	114
Feed Level			
3.2%	2.24	1.72	1.98
3.7%	1.82	1.48	1.54
4.2%	1.54	2.17	1.73

f) Weight by feed level interaction on F/W ratio in the ECR muscle (Study 2)

Weight (kg)	68	91	114
Feed Level			
3.2%	0.020	0.028	0.022
3.7%	0.021	0.031	0.032
4.2%	0.027	0.020	0.032

g) Weight by feed level interaction on N/W ratio in the ECR muscle (Study 2)

Weight (kg)	68	91	114
Feed Level			
3.2%	0.041	0.041	0.042
3.7%	0.039	0.041	0.044
4.2%	0.040	0.041	0.043

Table 30. (Cont'd)

h) Weight by feed level interaction on % nitrogen in the LD muscle (Study 2)

Weight (kg)	68	91	114
Feed Level			
3.2%	14.59	13.79	13.78
3.7%	13.81	13.80	13.65
4.2%	13.96	14.33	13.70

i) Weight by feed level interaction on N/F ratio in the LD muscle (Study 2)

Weight (kg)	68	91	114
Feed Level			
3.2%	2.27	1.50	1.65
3.7%	1.32	1.39	1.29
4.2%	1.39	1.64	1.28

j) Weight by feed level interaction on % ash in the ST muscle (Study 2)

Weight (kg)	68	91	114
Feed Level			
3.2%	4.65	5.04	4.82
3.7%	5.41	4.21	4.12
4.2%	4.45	4.66	4.42

nitrogen and water relative to fat than did the ECR muscle from pigs fed at the 3.2% and 4.2% levels of feeding.

This same pattern also held for percent fat and N/F ratio in the LD muscle and percentage fat in the OIA muscle. At 68 kg and 114 kg liveweight pigs fed at the 3.2% level had the smaller proportion of fat and greater proportion of nitrogen but at 91 kg liveweight pigs fed at the 4.2% level had the smaller proportion of fat and greater proportion of nitrogen compared to the other levels of feeding. Percentage ash in the ST muscle of pigs fed at the 3.7% level of feed decreased as liveweight increased but remained relatively constant in muscles from those fed at the 3.2 and 4.2% levels.

Breed x sex interactions ($P<0.05$) were observed for percent fat in the LD muscle and the N/F ratios in the RH muscle in pigs from Study 1 (Table 31a, b). In each breed group barrows had a higher percentage of fat in the LD muscle than gilts. Within the male sex group DY barrows had the highest percentage of fat in the LD muscle followed by HY and YY barrows but within the female sex group DY gilts had the lowest percentage fat and HY gilts the highest percentage. A similar pattern was observed for N/F ratios. Within sex groups DY barrows had the lowest N/F ratios and YY barrows the highest. DY gilts had the highest N/F ratios followed by YY and HY gilts.

Table 31.

a) Breed by sex interaction on % fat in the LD muscle (Study 1)

Sex		Barrow	Gilt
Breed	DY	28.53	16.90
	HY	25.77	21.64
	YY	21.93	18.04

b) Breed by sex interaction on N/F ratio in the RH muscle (Study 1)

Sex		Barrow	Gilt
Breed	DY	0.22	0.34
	HY	0.25	0.28
	YY	0.28	0.32

Breed x feed level interactions ($P<0.05$) were noted in Study 2 for the ECR, ST, OIA and RH muscles (Table 32a to j). For the ECR muscle, YL pigs fed at the 3.2% level and 4.2% level had a higher percentage of fat, lower percentage of nitrogen, lower N/F ratio and higher F/W ratio than the YLY breed group. At the 3.7% level of feeding positions were reversed between breed groups. For the ST muscle YL pigs had a greater percentage fat at all feeding levels than did the YLY pigs, however, the difference between the two breed groups was considerably less at the 3.7% level than at either the 3.2 or 4.2% levels. Percent nitrogen and the N/F and F/W ratios reflected the pattern observed in the ECR muscle. At the 3.2 and 4.2% levels of feeding, YL pigs had a lower percentage of nitrogen and N/F ratio and a higher F/W ratio than did YLY pigs. At the 3.7% level of feeding, YLY pigs were similar to YL pigs in percentage nitrogen, N/F ratio and F/W ratio.

In the OIA and RH muscles, YL pigs had the higher percentage fat and lower percentage nitrogen respectively at the 3.2 and 4.2% levels of feeding while the YLY pigs had the higher and lower percentages of each component at the 3.7% level of feeding.

Several interactions occurred among treatments in the five muscles for water, nitrogen and ether-extract when

Table 32.

a) Breed by feed level interaction on % fat in the ECR muscle (Study 2)

Breed	YL	YLY
Feed Level		
3.2%	9.57	6.86
3.7%	9.16	9.88
4.2%	10.50	7.20

b) Breed by feed level interaction on % nitrogen in the ECR muscle (Study 2)

Breed	YL	YLY
Feed Level		
3.2%	13.91	14.65
3.7%	14.13	14.15
4.2%	13.96	14.67

c) Breed by feed level interaction on N/F ratio in the ECR muscle (Study 2)

Breed	YL	YLY
Feed Level		
3.2%	1.61	2.34
3.7%	1.67	1.56
4.2%	1.40	2.22

d) Breed by feed level interaction on F/W ratio in the ECR muscle (Study 2)

Breed	YL	YLY
Feed Level		
3.2%	0.027	0.019
3.7%	0.027	0.030
4.2%	0.032	0.020

Table 32. (Cont'd)

e) Breed by feed level interaction on % fat in the ST muscle (Study 2)

Breed	YL	YLY
Feed Level		
3.2%	19.75	11.26
3.7%	17.75	15.24
4.2%	19.37	12.03

f) Breed by feed level interaction on % nitrogen in the ST muscle (Study 2)

Breed	YL	YLY
Feed Level		
3.2%	12.23	13.58
3.7%	12.91	12.95
4.2%	12.42	13.63

g) Breed by feed level interaction on N/F ratio in the ST muscle (Study 2)

Breed	YL	YLY
Feed Level		
3.2%	0.66	1.26
3.7%	0.88	0.89
4.2%	0.68	1.20

Table 32. (Cont'd)

h) Breed by feed level interaction on F/W ratio in the ST muscle (Study 2)

Breed	YL	YLY
Feed Level		
3.2%	0.068	0.037
3.7%	0.054	0.054
4.2%	0.067	0.037

i) Breed by feed level interaction on % fat in the OIA muscle (Study 2)

Breed	YL	YLY
Feed Level		
3.2%	10.62	8.51
3.7%	9.92	10.53
4.2%	12.21	9.41

j) Breed by feed level interaction on % nitrogen in the RH muscle (Study 2)

Breed	YL	YLY
Feed Level		
3.2%	11.51	12.58
3.7%	12.38	11.78
4.2%	11.82	12.56

expressed as ratios of ash. However, close inspection of the data indicated that all of the interactions among ratios which included ash were directly related to the differences in main effects already noted.

D) Discussion

Several of the studies already discussed have reported conflicting views as to the influence genetic and environmental factors may have on the normal deposition and relative changes in chemical components of the body. Some have reported a complete absence of any influence on chemical composition due to the effects of breed, sex or nutrition while others have stated firmly that such effects do influence chemical composition. In the studies reported here, all three factors appeared to affect both the rate of deposition and the relative proportions of chemical components of muscle.

In Study 1, HY pigs appeared to have a slightly greater proportion of fat and smaller proportions of moisture and nitrogen in all muscles than either DY or YY pigs although differences were only significant for the LD muscle ($P<0.05$). In Study 2, YL pigs had a higher percentage of fat, a lower percentage of nitrogen and lower N/F ratios for the ECR, LD, OIA and ST muscles indicating that, in these muscles, YL pigs were depositing fat at a more rapid rate than YLY pigs. In each study barrows appeared to have higher

concentrations of fat and lower concentrations of nitrogen in each muscle than gilts. Significant sex differences were noted for all muscles in Study 1 and for all muscles except ECR in Study 2. The effect of energy level and feeding levels were minimal. In Study 1 pigs fed the LE ration had a lower percentage of fat in the LD muscle than those fed the HE ration. In Study 2 pigs fed at the 3.2% level of feed intake had a lower percentage of fat in the LD muscle than those fed at the 3.7 or 4.2% levels. Several of these main effects were influenced by interactions and will be discussed later.

As growth proceeds from birth to maturity, increases in liveweight are accompanied by various physical and chemical changes in the carcass. In the early stages of post natal growth muscle is deposited at a more rapid rate than fat or bone but as liveweight increases a fattening stage is reached at which point the rate of fat deposition exceeds that of muscle. In the pig, major changes in the relative proportions of fat and muscle deposition occur at approximately 91 kg liveweight (Figure 1, Tables 1 and 2). These changes in physical growth are reflected by similar changes in chemical composition. Ulyatt and Barton (1963) and Brooks et al. (1964) have indicated very definite relationships between chemical and physical composition. The data from muscles in these studies were pooled to determine

if a similar relationship existed here. The results are presented in Figure 4. As liveweight increased from 23 to 114 kg, water, nitrogen and ash increased in a linear pattern. Fat, on the other hand, increased linearily to 91 kg liveweight but then increased at a more rapid rate than the other chemical components to 114 kg liveweight. Thus it would appear that the early growth of muscle and the later more rapid deposition of separable fat in the carcass correspond to the initial high concentrations of water and nitrogen in the muscle followed by a later more rapid deposition of intramuscular fat. On a relative basis, as liveweight increases, the percentage of muscle in the carcass and percentage moisture and nitrogen in the muscle decrease and percentage carcass fat and intramuscular fat increase.

The pattern of deposition depicted in Figure 4 can be influenced by several factors however. The interactions among liveweight, breed, sex and feeding regimes noted earlier appear to suggest that the relationship between nitrogen accretion and fat deposition in individual muscles vary considerably. For example in Study 1, HY pigs had a higher percentage of nitrogen in the RH muscle at 68 and 114 kg liveweight than DY or YY pigs but at 91 kg liveweight HY pigs had the lowest and YY pigs the highest percentage nitrogen (Table 28a). Comparing the N/F ratios of these

breeds indicates that HY and YY pigs had similar amounts of nitrogen and fat in the RH muscle at 68 kg liveweight but that between 68 and 91 kg liveweight HY pigs were depositing more fat and less nitrogen than YY pigs. Between 91 and 114 kg liveweight these positions were reversed with HY depositing the greater amount of nitrogen and YY the greater amount of fat. In Study 2, pigs fed at the 3.2% level had greater concentrations of nitrogen and smaller concentrations of fat in the ECR and LD muscles at 68 and 114 kg liveweight than did those fed at the 3.7 and 4.2% levels of feeding. AT 91 kg liveweight those pigs fed at the 4.2% level of feeding had the greatest concentration of nitrogen and smallest concentration of fat in these two muscles (Table 30a, b). Fat deposition in these two muscles increased most rapidly between 68 and 91 kg liveweight for those pigs fed at the 3.2% level and between 91 and 114 kg for those pigs fed at the 4.2% level of feeding. These interactions would seem to indicate that in some instances fat deposition may exceed nitrogen accretion at much earlier liveweights than 91 kg indicated earlier. These results may also be a faint reflection of a phasic growth pattern of nitrogen and fat. In each of the above muscles, the rate of nitrogen deposition exceeded that of fat up to 68 kg liveweight, was less than fat between 68 and 91 kg and again exceeded that of fat between 91 and 114 kg liveweight in those pigs fed at the 3.2% level. While increases and

decreases in concentration of nitrogen and fat occurred at different points for pigs fed at 3.7 or 4.2% levels of feeding, a phasic pattern appeared to also occur at these levels.

The relationship of intramuscular fat and total separable carcass fat has long been debated. Doornenbal (1967) and Duniec (1961) have each indicated that there is little correlation between intramuscular and total separable fat in the carcass. The data here can not be used to either verify or deny these conclusions but they do suggest interesting patterns.

In Study 1 DY pigs had the most separable fat in the carcass and HY the least but percent fat in the LD muscle of DY pigs was less than that of HY pigs. The largest contributing factor to this difference was due to the very small proportion of fat in the LD muscle of DY females. Pigs fed the LE ration had less separable carcass fat than those fed the HE ration but as liveweight increased from 68 to 114 kg LE fed pigs had a higher percentage of intramuscular fat in the ECR muscle than HE fed pigs.

In Study 2, no differences were noted in the relative proportions of carcass fat between breed groups but the YL breed group had a higher proportion of fat extract in the ECR, LD, OIA and ST muscles than did the YLY breed group. On

the other hand, more positive relationships between intramuscular and total dissectible fat were noted in sex comparisons. In each study barrows had both a greater proportion of dissectable fat and a greater proportion of intramuscular fat in most muscles. As well, pigs fed at the 3.2% level in Study 2 had both smaller amounts of separable carcass fat and smaller concentrations of intramuscular fat in the LD muscle compared to those fed at the 3.7 and 4.2% levels. However, as already noted these differences varied and reversed depending on liveweight. From these observations it would appear that intramuscular fat is poorly related to dissectible fat in the carcass and may be influenced to a considerable degree by genetic and nutritional factors. Suess et al. (1969) reported considerable variation in intramuscular fat relative to feeding regime. Johnson et al. (1972, 1973) have indicated that, in cattle, as percent dissectable fat increased from 5% at birth to approximately 21% of carcass weight, intramuscular fat as a percentage of total carcass fat decreased and then remained relatively constant in both total muscle and muscle groups despite increased levels of total fat.

Whether or not intramuscular fat makes any significant contribution to muscle weight and distribution has often been questioned. Johnson et al. (1973) could find no

difference in the muscle distribution of cattle when fresh muscles were compared to muscles minus the weight of ether-extract. Suess et al. (1969) found no difference in growth of muscles compared on a fresh weight, fat-free weight or fat-free dry weight. In an earlier report (Richmond and Berg, 1971b) it was suggested that differences observed among DY, HY and YY pigs in percent spinal muscle might be due to differences in intramuscular fat concentrations. DY pigs had the greater percentage of muscle in this muscle group but were found here to have also had the smallest concentrations of intramuscular fat in the largest muscle of this group, the LD muscle. Intramuscular fat probably had little influence on these breed differences in muscle distribution. In Study 2, YL pigs had similar proportions of total muscle in the proximal pelvic limb, smaller proportions of total muscle in the spinal and distal thoracic limb and a greater proportion of muscle in the abdominal muscle group compared to YLY pigs. The ST, LD, ECR and OIA muscles which represent these muscle groups respectively each had a greater concentration of intramuscular fat in the YL pigs than in the YLY pigs. From this it would appear that intramuscular fat may contribute little to total muscle weight or to similarities or differences in muscle weight distribution.

Individual muscles in these studies were not compared

to test statistical differences that might exist among them in concentrations of the different chemical components. However, pooling the data over liveweights did reveal a fairly consistent order in chemical composition of the muscles in each study. Table 33 ranks the muscles according to the different proportions and concentrations of water, nitrogen and fat. As noted in muscle groups by Pryor and Warren (1973), the individual muscles here show an inverse relationship in chemical composition. Those muscles with the greatest concentrations of water have the smallest concentrations of fat. A similar relationship exists between water and nitrogen but is not as pronounced. The ECR muscle had the greatest concentration of water and nitrogen and the smallest concentration of fat while the RH muscle had the greatest concentration of fat and smallest concentration of water and nitrogen.

Pryor and Warren (1973) have indicated that differences between muscles in concentrations of intramuscular fat may be due to differences in the rate of blood circulation through the muscle and to differences in muscle function. Those muscles having a slow circulation rate have a higher concentration of fat than those with a more rapid rate of circulation. Muscles which are very active have less intramuscular fat than those that are relatively inactive. Johnson et al. (1972) and Pryor and Warren (1973) found that

Table 33. Muscles ranked in decreasing order of relative proportion of nitrogen, water and fat averaged over three liveweights (Studies 1 and 2)

	Percent			Weight Ratio		
	Nitrogen	Water	Fat	N/W	N/F	F/W
Study 1	ECR	ECR	RH	LD	ECR	RH
	OIA	OIA	LD	OIA	OIA	LD
	ST	ST	ST	ST	LD	ST
	LD	LD	OIA	ECR	ST	OIA
	RH	RH	ECR	RH	RH	ECR
Study 2	ECR	ECR	RH	LD	ECR	RH
	LD	OIA	ST	OIA	LD	LD
	OIA	ST	OIA	ST	OIA	ST
	ST	RH	LD	ECR	ST	OIA
	RH	LD	ECR	RH	RH	ECR

muscles in the hind limb and fore shin, responsible for locomotion, had the least intramuscular fat, while abdominal muscles, serving a passive support function, had the most intramuscular fat. In this study the ECR muscle was the smallest and the most active muscle and had the least concentration of fat. The RH muscle is both a support and contraction muscle and one which might be expected to have less fat than reported here. However, Johnson et al. (1973), when comparing individual muscles and muscle groups in cattle, found that of the five muscles studied here, RH also had the greatest concentration of fat. This may indicate that the RH muscle is a relatively sedentry muscle. The ST, OIA and LD muscles from the studies presented here were intermediate in fat concentration between the ECR and RH but changed in position of ranking between Studies 1 and 2. The function of the LD muscle is that of support and extension, the ST muscle is that of support and propulsion and the OIA that of support and compression. All of these muscles act to a greater or lesser degree in support and contraction and, relative to their size, may experience similar degrees of activity.

Functional difference may also be a contributing factor to differences in muscle composition between species. Terrell et al. (1969) and Lawrie (1961b) reported that in cattle the psoas major muscle had a greater percentage of

fat than the LD muscle but Allen et al. (1967), Lawrie et al. (1963) and McMeekan (1940a) indicated that in pigs, percent fat in the LD muscle exceeded that of the psoas major muscle. In cattle the LD muscle and psoas major muscle make up 6.6 and 1.7% of total muscle respectively (Butterfield and May, 1965), while in pigs comparable percentages for these two muscles are 10.8 and 1.7% respectively (Table 18). The greater divergence in relative size of these two muscles in pigs compared to cattle may be due to functional differences and activity. In cattle the psoas major muscle may be more sedentry than the LD muscle, while in pigs, the psoas major muscle may be more active than the LD muscle.

A third factor which may have some influence on chemical composition of a muscle is the relative growth impetus of the muscle. Those muscles having a high relative growth rate to total muscle might be expected to be depositing nitrogen more rapidly than fat compared to those muscles of low or average relative growth impetus. In these studies the ECR muscle had a low-high or average-high growth impetus and contained the greatest concentration of nitrogen and smallest concentration of fat compared to other muscles. On the other hand, the RH muscle was classified as having an average or low-average growth impetus indicating that any major spurts in growth were already completed. As evidenced

by the N/F ratios in Tables 26 and 27, fat concentration relative to that of nitrogen was greatest in this muscle. The relative growth patterns of the OIA muscle was average and those of the LD and ST muscles high-average. These muscles had apparently already gone through a high growth phase followed by a growth phase relative to that of total muscle. As growth receeded from high to average, the rate of nitrogen deposition would have decreased and that of fat increased. These muscles were intermediate in N/F ratios to the more rapidly growing ECR muscle and much slower growing RH muscle. As a muscle of average growth impetus, the OIA might have been expected to have concentrations of nitrogen and fat more closely related to the RH muscle than the ECR muscle as shown here (Tables 26 and 27). However, this muscle may not be properly classified here since Davies (1973) did suggest a high growth impetus classification for the OIA. If Davies' classification is considered then one would expect the OIA to be similar to the ECR in nitrogen and fat concentration.

The relative growth impetus of a muscle is directly related to its function so that chemical composition of the muscle may be more related to function than to growth impetus. However, some caution may be required when comparing chemical composition of muscles within and between animals, that comparisons are made at the same relative

stages of growth.

It would appear from these and other studies that evolutionary functional differences of individual muscles may be the primary regulating factor of chemical composition.

General Summary and Conclusions

Two studies were undertaken to assess some of the physcial and chemical aspects of tissue growth in swine. One hundred and eighty one barrows and gilts representing five breed groups were fed either high or low energy rations or different levels of one low energy ration and slaughtered at 23, 68, 91 or 114 kg liveweight.

Tissue Growth

The relative growth patterns of the major carcass tissues in pigs were observed to be similar to those in other domestic species. Bone growth was relatively slow and muscle growth relatively fast. Fat deposition paralleled muscle growth up to 91 kg liveweight and thereafter exceeded muscle growth in absolute amount. Liveweight appeared to be a determining factor in the relative proportions of muscle, fat and bone in the carcass.

Pigs which were fed rations low in both energy and protein on a restricted basis were older than pigs fed more liberal levels of higher energy and protein rations but were similar in carcass composition at predetermined slaughter weights. Within treatment groups increasing energy levels or the level of feeding resulted in increases in the proportion of fat and decreases in the proportion of muscle in the carcass.

Carcasses from gilts contained a greater proportion of muscle and less of fat than barrows. Only slight differences were noted among breed groups in carcass composition.

Interactions among main effects indicated differences in energy intake and partitioning of nutrients for tissue growth. Barrows, pigs fed high energy rations or high levels of feed and strains of pigs with a predisposition to fattening were similar in carcass composition at 91 kg liveweight to gilts, pigs fed low energy rations or low levels of feed and strains of pigs with a predisposition to muscle growth at 114 kg liveweight.

Present grading standards do not recognize carcass merit outside a very narrow range in liveweights. It is possible that extending the weight ranges would afford pig producers alternative management and marketing opportunities.

Relative Growth Patterns and Distribution of Muscle

Slight changes occurred in muscle distribution between 23 and 68 kg liveweight with little change thereafter. Only minor differences were noted in muscle distribution due to the effects of breed, sex, ration or feeding level. Interactions were observed for weight by feeding level, breed by feeding level and weight by breed effects for some muscle groups.

Of the 96 muscles dissected, 69 muscles each weighed less than 1% of total muscle. Growth impetus patterns of individual muscles and muscle groups were compared with those from cattle and sheep. Thirty-three muscles and 3 muscle groups were classified as diphasic and 23 muscles as either mono or diphasic in pigs. In cattle, 23 muscles and 7 muscle groups were classified as diphasic and 33 muscles and 4 muscle groups were classified as diphasic in sheep. Generally muscle growth in pigs appeared to be more monophasic than in cattle or sheep although this difference may have been due to differences in starting points and degree of maturity.

Relative growth impetus of muscles and subsequent muscle distribution appeared to be dependent on muscle function. Muscles responsible for mobility immediately after birth, such as the distal limb muscles which are well developed at birth, had a low growth impetus relative to total muscle. Those muscles responsible for propulsion as mobility increases, such as the proximal limb muscles, had a high growth impetus. Posture muscles, such as those muscles around the spinal column, had an average growth impetus indicating growth relative to that of total muscle. The relative growth impetus of the abdominal muscles appeared to be dependent in part on feed intake.

Because relative growth and distribution of muscle appears to be directly related to functional requirements it is unlikely that within any one species functional requirements could be changed enough to result in major changes in muscle distribution. However, some manipulation might be possible through the use of very diverse breeds or the regulation of androgen levels. Further studies of muscle growth and distribution should be directed towards determining the various genetic and biochemical controls which regulate the development of this tissue.

Growth of Chemical Components in Muscle

From these data it appeared that the early growth of muscle and later more rapid deposition of separable fat in the carcass were accompanied by initial high concentrations of water and nitrogen in the muscle followed by a later more rapid deposition of intramuscular fat. As liveweight increased percentage muscle in the carcass and percentage moisture and nitrogen in the muscle decreased while percentage carcass fat and intramuscular fat increased.

In Study 1 breed differences in chemical composition of muscle were minor but in Study 2 YL pigs appeared to have higher concentrations of fat and lower concentrations of nitrogen in all muscles except the LD muscle than YLY pigs.

Barrows appeared to have higher concentrations of fat

and lower concentrations of nitrogen in each muscle than gilts.

The effects of energy levels and feeding levels were minimal. In Study 1 pigs fed the LE ration had a higher percentage of fat in the LD muscle than those fed the HE ration. In Study 2 pigs fed at the 3.2% level of feed had a lower percentage of fat in the LD muscle than those fed at either the 3.7 or 4.2% levels.

Fat concentration in a muscle appeared to be related to muscle function and growth impetus. The more active ECR muscle with a low-high or average-high growth impetus contained the greatest concentration of nitrogen and smallest concentration of fat. The more sedentry RH muscle with an average or low-average growth impetus contained the greatest concentration of fat and smallest concentration of nitrogen. The OIA, LD and ST muscles were intermediate in activity and had gone through an early growth spurt resulting in concentrations of nitrogen and fat intermediate to the ECR and RH muscles.

Because of the relationship between muscle function, growth impetus and chemical composition comparisons may have to be made at the same relative stage of growth.

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Appendix

Tables containing means and standard errors of chemical component weights of five muscles for studies 1 and 2.

Table 1. Means and standard errors of chemical component weights (g) of 5 muscles as influenced by liveweight, breed, sex and ration (Study 1)

	Liveweight (kg)					Breed				Sex			Ration		
	23*	68	91	114	SE	DY	HY	YY	SE	Barrow	Gilt	SE	HE	LE	SE
Weight water (g)															
M. Extensor Carpi Radialis	20.40	52.76^{a}	60.81^{b}	72.57^{c}	2.154	62.17	62.44	61.54	2.154	58.59^{a}	65.50^{b}	1.759	61.13	62.97	1.759
M. Longissimus Dorsi	379.97	738.97^{a}	894.41^{a}	1238.60^{b}	105.563	860.93	1104.20	906.83	105.563	1015.60	899.04	87.009	905.50	1009.10	87.009
M. Obliquus Internus Abdominis	40.08	108.26^{A}	123.26^{B}	149.49^{C}	2.803	130.41^{A}	133.56^{A}	117.03^{B}	2.803	122.95^{a}	131.05^{b}	2.289	122.95^{a}	131.05^{b}	2.289
M. Rhomboideus	36.29	86.42^{A}	106.13^{B}	118.19^{C}	3.221	109.83^{A}	105.75^{A}	95.15^{B}	3.221	99.86$_{A}$	107.30$_{B}$	2.630	102.64$_{A}$	104.52$_{B}$	2.630
M. Semitendinosus	69.51	194.98^{A}	248.37^{B}	297.36^{C}	5.345	254.13	244.07	242.52	5.345	234.07^{A}	259.73^{B}	4.364	237.41^{A}	256.40^{B}	4.364
Weight dry matter (g)															
M. Extensor Carpi Radialis	5.65	16.09^{A}	19.44^{B}	23.36^{C}	0.674	19.25	20.35	19.29	0.674	18.84	20.42	0.551	19.50	19.76	0.551
M. Longissimus Dorsi	119.50	276.07^{A}	338.31^{A}	486.35^{B}	39.619	338.02	418.29	344.42	39.619	400.69	333.14	32.349	355.62	378.20	32.349
M. Obliquus Internus Abdominis	11.09	37.65^{A}	45.84^{B}	54.69^{C}	1.378	46.68^{A}	48.99^{A}	42.51^{B}	1.378	45.15	46.97	1.125	45.32	46.80	1.125
M. Rhomboideus	12.35	37.19^{A}	44.82^{B}	54.93^{C}	0.799	48.41^{A}	47.88^{AB}	40.64^{B}	0.799	46.14^{A}	45.15^{B}	0.653	46.02^{A}	45.27^{B}	0.653
M. Semitendinosus	19.79	68.84^{A}	89.40^{B}	113.18^{C}	1.751	94.62^{A}	90.36^{AB}	86.43^{B}	1.751	87.43^{A}	93.52^{B}	1.430	87.37^{A}	93.57^{B}	1.430
Weight nitrogent (g)															
M. Extensor Carpi Radialis	.74	2.13^{A}	2.54^{B}	3.10^{C}	0.101	2.55	2.65	2.57	0.101	2.46	2.72	0.824	2.54	2.64	0.824
M. Longissimus Dorsi	14.60	32.30^{B}	39.58^{AB}	56.82^{B}	4.695	39.73	48.42	40.56	4.695	45.35	40.45	3.834	40.56	45.24	3.834
M. Obliquus Internus Abdominis	1.46	4.56^{A}	5.50^{B}	6.58^{C}	0.145	5.73^{a}	5.78^{a}	5.12^{b}	0.145	5.35^{a}	5.74^{b}	0.119	5.40	5.69	0.119
M. Rhomboideus	1.25	3.52^{A}	4.28^{B}	5.02^{C}	0.098	4.52	4.43	3.87	0.098	4.10$_{A}$	4.45$_{B}$	0.080	4.26	4.29$_{B}$	0.080
M. Semitendinosus	2.57	8.08^{A}	10.19^{A}	13.03^{B}	0.650	11.05	10.20	10.04	0.650	9.92^{A}	10.94^{B}	0.620	10.00	10.86^{B}	0.620
Weight fat (g)															
M. Extensor Carpi Radialis	.60	1.88^{A}	2.26^{A}	3.89^{B}	0.154	2.55	2.94	2.54	0.154	2.88^{a}	2.48^{b}	0.126	2.59	2.76	0.126
M. Longissimus Dorsi	22.12	54.69^{A}	68.49^{A}	121.49^{B}	10.411	78.65	95.38	70.64	10.411	96.42^{a}	66.69^{b}	8.500	84.15	78.97	8.500
M. Obliquus Internus Abdominis	1.28	6.07^{A}	9.08^{B}	11.08^{C}	0.106	7.99$_{A}$	10.24$_{A}$	8.01$_{A}$	0.106	8.94	8.55$_{B}$	0.860	8.53	8.96	0.860
M. Rhomboideus	3.46	13.07^{A}	15.52^{A}	21.41^{B}	0.837	17.86^{A}	18.07^{A}	14.08^{B}	0.837	18.12^{a}	15.21^{b}	0.683	17.29	16.04	0.683
M. Semitendinosus	2.59	13.43^{A}	18.87^{A}	28.25^{B}	1.438	20.94	21.25	18.45	1.438	21.18	19.31	1.174	19.86	20.57	1.174
Weight ash (g)															
M. Extensor Carpi Radialis	.26	.67^{A}	.78^{AB}	.95^{B}	0.059	.87	.78	.75	0.059	.74	.86	0.048	.76	.86	0.048
M. Longissimus Dorsi	6.24	11.83	14.69	19.79	2.801	15.15	17.76	13.41	2.801	14.93	15.95	2.287	14.38	16.50	2.287
M. Obliquus Internus Abdominis	.52	1.59	1.70	2.17	0.176	1.99	1.93	1.54	0.176	1.77	1.87	0.144	1.73	1.91	0.144
M. Rhomboideus	.47	1.25	1.60$_{AB}$	1.62$_{B}$	0.133	1.58	1.54	1.36	0.133	1.39	1.60	0.109	1.46	1.52	0.109
M. Semitendinosus	1.04	2.93^{A}	3.67^{AB}	4.37^{B}	0.367	4.34	3.55	3.08	0.367	3.34	3.98	0.300	3.43	3.88	0.300

a, b, c and A, B, C - means within the same classification followed by different letters differ significantly at $P<0.05$ and $P<0.01$ respectively.

*23 kg group not included in the statistical analysis

Table 2. Means and standard errors of chemical component weights (g) of 5 muscles as influenced by liveweight, breed, sex and feeding level (Study 2)

	Liveweight (kg)				Breed			Sex			Feeding Level			
	68	91	114	SE	YL	YLY	SE	Barrow	Gilt	SE	3.2%	3.7%	4.2%	SE
Weight Water (g)														
M. Extensor Carpi Radialis	50.93^{A}	66.82^{B}	78.26^{C}	1.190	62.42^{a}	68.25^{b}	0.972	63.24^{a}	67.43^{b}	0.972	67.02	65.63	63.36	1.190
M. Longissimus Dorsi	967.27^{A}	1246.70^{B}	1506.00^{C}	22.058	1186.7^{A}	1293.30^{B}	18.010	1172.90^{A}	1307.10^{B}	18.010	1277.50	1233.90	1208.50	22.058
M. Obliquus Internus Abdominis	95.04^{A}	127.84^{B}	148.34^{C}	2.196	123.97	123.51	1.793	121.10^{A}	126.38^{B}	1.793	122.34	125.05	123.82	2.196
M. Rhomboideus	91.20^{A}	121.58^{B}	147.69^{C}	2.946	122.11	118.20	2.406	117.31	123.00	2.406	121.94_{B}	121.45_{AB}	117.08_{A}	2.946
M. Semitendinosus	198.62^{A}	264.29^{B}	317.03^{C}	4.668	257.87	262.08	3.811	256.89	263.06	3.811	270.45^{B}	258.30^{AB}	251.19^{A}	4.668
Weight Dry Matter (g)														
M. Extensor Carpi Radialis	14.07^{A}	19.30^{B}	23.99^{C}	0.358	18.33^{A}	19.91^{B}	0.292	18.68^{a}	19.57^{b}	0.292	19.52_{b}	19.37_{ab}	18.47_{a}	0.358
M. Longissimus Dorsi	312.01^{A}	427.96^{B}	528.38^{C}	7.503	405.88^{A}	440.08^{B}	6.126	410.10	435.86	6.126	436.75^{b}	422.98^{ab}	409.21^{a}	7.503
M. Obliquus Internus Abdominis	28.29^{A}	38.66^{B}	46.62^{C}	0.743	38.67	37.05	0.606	37.79^{a}	37.91^{b}	0.606	37.25	38.36	37.97	0.743
M. Rhomboideus	29.80^{A}	40.30^{B}	51.27^{C}	1.306	42.14_{a}	38.77_{b}	1.066	40.19	40.72	1.066	41.93_{B}	39.89_{AB}	39.55_{A}	1.306
M. Semitendinosus	59.76^{A}	85.63^{B}	108.30^{C}	1.639	86.99^{a}	82.14^{b}	1.338	84.72	84.41	1.338	87.93^{B}	84.54^{AB}	81.22^{A}	1.639
Weight Nitrogen (g)														
M. Extensor Carpi Radialis	2.04^{A}	2.73^{B}	3.38^{C}	0.050	2.56^{A}	2.87^{B}	0.041	2.64^{a}	2.79^{b}	0.041	2.78_{b}	2.73_{a}	2.64_{a}	0.050
M. Longissimus Dorsi	44.04^{A}	59.80^{B}	73.34^{C}	1.053	55.61^{A}	61.85^{B}	0.859	56.21^{A}	61.25^{B}	0.859	61.09^{b}	58.02^{a}	57.07^{a}	1.053
M. Obliquus Internus Abdominis	3.93^{A}	5.44^{B}	6.29^{C}	0.106	5.24	5.20	0.086	5.15	5.29	0.086	5.17	5.27	5.22	0.106
M. Rhomboideus	3.49^{A}	4.99^{B}	6.12^{C}	0.115	4.92	4.81	0.094	4.73	5.00	0.094	4.98_{b}	4.87_{ab}	4.74	0.115
M. Semitendinosus	7.88^{A}	11.19^{B}	13.53^{C}	0.202	10.78	10.95	0.165	10.73	11.00	0.165	11.25^{b}	10.85^{ab}	10.49	0.202
Weight Fat (g)														
M. Extensor Carpi Radialis	1.17^{A}	1.73^{B}	2.21^{C}	0.109	1.80	1.60	0.089	1.69_{a}	1.71_{b}	0.089	1.86	1.89	1.65	0.109
M. Longissimus Dorsi	30.36^{A}	42.17^{B}	58.79^{C}	2.757	45.52	42.02	2.251	47.78^{a}	39.76^{b}	2.251	38.97	47.42	44.92	2.757
M. Obliquus Internus Abdominis	3.17^{A}	3.54^{A}	5.76^{B}	0.324	4.77^{A}	3.54^{B}	0.264	4.67^{A}	3.62^{B}	0.264	4.00	4.07	4.39	0.324
M. Rhomboideus	7.04^{A}	8.17^{A}	11.35^{B}	0.748	10.03^{a}	7.68^{b}	0.611	9.25^{a}	8.46^{b}	0.611	9.36	8.08	9.12	0.748
M. Semitendinosus	8.86^{A}	13.42^{B}	19.87^{C}	0.935	16.86^{A}	11.24^{B}	0.764	15.15^{a}	12.95^{b}	0.764	14.53	14.46	13.16	0.935
Weight Ash (g)														
M. Extensor Carpi Radialis	$.67^{A}$	$.94^{B}$	1.16^{C}	0.026	.91	.94	0.021	.92	.92	0.021	.95	.93	.89	0.026
M. Longissimus Dorsi	15.28^{A}	20.96^{B}	24.06^{C}	0.690	19.33	20.87	0.564	20.18	20.02	0.564	21.22	19.87	19.22	0.690
M. Obliquus Internus Abdominis	1.30^{A}	1.82^{B}	2.11^{C}	0.033	1.77	1.71	0.027	1.72	1.77	0.027	1.77_{b}	1.73_{ab}	1.73_{a}	0.033
M. Rhomboideus	1.23^{A}	1.86^{B}	2.12^{C}	0.074	1.81	1.67	0.061	1.74	1.73	0.061	1.89^{B}	1.70^{AB}	1.62^{A}	0.074
M. Semitendinosus	3.03^{A}	4.18^{B}	5.06^{C}	0.143	4.13	3.96	0.116	4.07	4.12	0.116	4.50^{B}	3.96^{AB}	3.71^{A}	0.143

a, b, c and A, B, C - means within the same classification followed by different letters differ significantly at $P<0.05$ and $P<0.01$ respectively.